MECHANICAL INVENTIONS
OF TO-DAY

Mechanical Inventions of To-day

INTERESTING DESCRIPTIONS OF MODERN MECHANICAL INVENTIONS TOLD IN NON-TECHNICAL LANGUAGE

BY

THOMAS W. CORBIN

AUTHOR OF "ENGINEERING OF TO-DAY," &c. &c.

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NOTE

The author wishes to express his indebtedness to the firms who have assisted him with the loan of photographs for illustrations and in other ways. In the case of the half-tone illustrations the names of the lenders are duly acknowledged in the inscriptions, but there are several in the text where the names could not be conveniently printed. These are as follows:—

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The author also wishes to make it clearly understood that many of the diagrams and illustrations which have been made specially for this book are not intended for accurate working drawings, but have been simplified so as to show the general principles of the inventions, while avoiding details which would only serve to confuse the general reader.

Mechanical Inventions of To-day

CHAPTER I

INVENTION

The earliest invention of which there is any record was made a hundred thousand or more years ago. It was before the time of Patent Offices, so we have no chance of purchasing a copy of the specification, the detailed description which every inventor nowadays who wants to "protect" his invention has to furnish. We have a better record than that, however, for we have the actual implements themselves which were made under the invention.

Being of imperishable material, they have lasted all these ages, while far more modern things have long since corroded away. Moreover, we need not seek these interesting relics of the dawn of civilization on the banks of the Euphrates or any of those other sites where the wonders of antiquity are so plentifully revealed. They are to be found in abundance in the British Isles.

I am referring, of course, to the neatly chipped stone tools made by the men of the "Old Stone Age," some of which are illustrated on page 18.

It seems probable that the chipped flint scraper was the earliest of these, and simple though it seems to us in these enlightened days, it must have been a genius who first thought of making it. No doubt it originated in a discovery, as most inventions do. Some man discovered that he could clean the flesh off a skin of a dead animal with a broken flint. Possibly he accidentally scraped some of his own skin off on such a stone, and that suggested its use for the other purpose. Then when the supply of the accidentally broken stones failed, someone tried to break them on purpose. Gradually more and more skill was attained until someone hit upon the idea of chipping the flint on both sides and so forming the sharp edge of the knife instead of the square edge of the scraper.

It is possible to find the sites of veritable factories where the manufacture of flint implements was carried on. There can be unearthed not only finished articles, but the chips which fit them, showing that they were made at the very spot where they have lain all these years. There are "wasters," too, articles which were spoiled in process of manufacture and then thrown aside.

Other tools are found along with these things which were evidently used in the fashioning of them. Large, round stones, which have been bruised a great deal, as the marks upon them show, were evidently the hammers of these ancient craftsmen. These were evidently used to strike upon others, called by archæologists "fabricators," the purpose of which was that of the chisel.

Thus we can picture these earliest workmen of whom we have any trace, holding a piece of flint, probably between their knees, and fashioning it by means of a

fabricator held in one hand and struck by a hammer held in the other.

The age at which all this occurred is fixed by the strata in which the things are found buried, and from that geologists are able to put it as far back as hundreds of thousands of years.

From this dim, far-off beginning, down to the present time, men have been inventing things, and inventive activity was never greater than at the present day. In the year 1617, when the records of the British Patent Office commence, there were only five patents granted, and several of them were not really for inventions, but simply privileges granted to favoured people. In the year 1904, however, the number had grown to 16,000, while in the United States the number was 31,000.

At the basis of all inventions of a mechanical nature, all those, that is, which we are concerned with in this book, are a small number of elementary principles. The lifting power of the screw, the splitting power of the wedge, the way in which a lever can convert a weak but ample movement into a small but powerful one; all these and a number of others have been known from very ancient times. Others, such as the power to be obtained by expanding substances by heat, are more modern, but are now well known. Few modern inventions, therefore, exhibit anything new in principle. It is almost entirely in the adaptation of the old ideas to modern needs that the mechanic of to-day can exercise his powers of invention.

This he does mainly in the direction of simplifying. Simplicity is the hall-mark of a good invention. Within reasonable limits, any clever mechanic can devise a

machine to do anything, provided you do not mind its being very complicated; but a genius comes along and does the same thing in a simple manner. Then an outsider sees it and thinks nothing of it because it is so simple. The really great invention is the one which, when it has once been made, sets everybody saying, "How strange that everybody did not see that long ago."

A notable instance of this is to be found in Watt's "parallel motion," a simple arrangement of four rods jointed together. It is shown in Fig. 1, and no one looking at that diagram would think it anything extraordinary. Yet it is an example of a difficult result, perfectly achieved, by the simplest possible mechanism. Watt himself is said to have regarded it as his cleverest invention, and it has earned the enthusiastic admiration of the greatest engineers.

The problem to be solved was this. In the old Cornish engine, which was created by Watt, there was a large beam, and to the end of that beam there was attached the end of a vertical rod. The beam rocked upon a centre, and so its end described a curve, a part of a circle in fact. Yet the rod needed to rise and fall in a perfectly vertical direction. Had it been merely attached by a pivot to the end of the beam the swinging action of the beam would have forced it from side to side, a thing which was not permissible. Moreover, between the centre of the beam and the end there was attached another rod which also needed to go straight up and down.

That was the problem. Now let us examine the solution. In Fig. 1, A is one half of the great beam of the engine, which rocks upon the pivot B. The end C, therefore, describes a curve, while the rod D must go up and

down in a straight line. The latter is connected to the beam by the short rod E, while a little nearer the centre of the beam there hangs down another rod, F, exactly the same length as E. Their lower ends are connected together by a fourth rod, G, which is just as long as the pivots at the upper ends of E and F are apart. Finally, the junction of F and G is connected by a rod H to a fixed

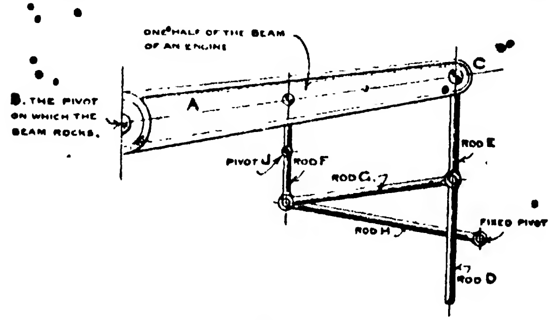


Fig. 1.

A MODEL OF SIMPLICITY.

This simple arrangement of rods is the "parallel motion," the cleverest achievement of the prince of inventors, James Watt. The end of the beam moves through *a curve,* but the rod D, because of the arrangement of rods, moves in *a straight line.*

point on the frame of the engine or the wall of the engine-house. The rod H must bear a certain proportion to the length of the beam.

The essential parts of the apparatus are the three rods E, F, and G (which together with a part of the beam form the parallelogram which gives the apparatus its name), and the rod H.

As the end of the beam swings up and down it describes a curve; so, too, does the left-hand end of the rod H, but the opposite way; and the combination of these two

motions causes the upper end of the rod H to be guided up and down in a perfectly straight line.

Moreover, there is a certain point, J, in the rod F which also moves up and down vertically; so that if the second vertical rod (which for clearness sake I have not shown in the diagram) be pivoted upon it there, it, too, will be guided in the same straight manner.

Perhaps to realize the beauty of this contrivance one needs to see it at work (a thing which is not difficult, for it is in use at many waterworks); but even on paper it is easy to see what a triumph of ingenuity it is, and the enthusiastic praise which has been bestowed upon it by competent judges proves the truth of what I have been trying to show, namely, that generally speaking, the simpler the contrivance the greater is its cleverness as an invention.

And that constitutes one of my difficulties in this book. A man who has been interested in mechanical matters all his life can realize the beauty of simplicity; but how am I to convey that idea to the general reader whose life has led him into other paths than engineering and who may not appreciate this point?

Perhaps such may be induced to understand this better if it be put in this way. There is a certain amount of experience common to all mechanics. Certain things have been done in certain ways for a long time, and in all probability will always be done in that way. That is because finality has undoubtedly been reached along certain lines. For example, the making of holes, the forming of things accurately round, or of wheels which will turn without any wobble sideways, are things which are always made by turning round: either turning the

article round in a lathe or else turning the tool which is operating upon it in a drilling machine. However it is done, something has got to go round and round. That is the fundamental idea of all such operations, and it seems as if there is no possible better way. Finality has been reached in that direction. There may be improvements in machinery and tools used for the work, but the main idea, it seems, will never be improved upon. Thus there is a certain stratum of never-varying ideas underlying the engineer's methods, and there is a great temptation to include among these more than ought to be included. To that must be added also the natural conservatism of the human race, the instinctive appeal for a precedent. Precedents are supposed to be specially dear to the lawyer and the civil servant, but they are dear to us all. And rightly so, for they represent the accumulated experience of all our predecessors; the trouble arises when we let them become our masters instead of our helpers, and all of us do that to a certain extent.

Thus, whenever a problem is presented to an engineer, his mind goes back unconsciously to the similar jobs which he has seen or heard of, and along those lines he begins to work. Then, having once started on those lines, nothing but a very determined effort on his part will ever enable him to cast the past aside and think the thing out on original lines of his own. The result of this is that we are apt to encumber anything new with unnecessary complications, just because they have been used before. An example of this which comes to mind is the case of the railway. Nearly all the early experimenters with the steam locomotive assumed that to enable it to pull a load the rails would need to have teeth and the engine

a tooth wheel to work in them. It was not until a great deal of time and money had been spent on the matter that it was realized that smooth wheels would grip smooth rails sufficiently to enable an engine to pull a train on any ordinary line.

In order, then, to appreciate the worth of an invention one really needs to know something of the temptations which the inventor had to resist to follow precedents.

A further point in which the really great inventor reveals himself is this. Many a thing goes on well up to a point and then fails because of something in itself quite trifling. It is the avoidance of little pitfalls like this to which I refer. I used to know an engineer of eminence in the telegraph and telephone branch of the profession, and I well remember the enthusiasm with which he pointed out to me a very trifling point in the early wireless telegraph instrument. It was trifling in itself, but it meant much to the success of the apparatus.

One of the earliest forms of receiver used in wireless telegraphy was the Branley Coherer. It consists of a small tube with some metal filings in the middle. Under normal conditions these filings lie loosely, and then they do not form a good conductor of electricity. If the apparatus be struck, however, by the ethereal waves which convey the "wireless" messages, the filings cohere together and then they form a good conductor. Thus, if we connect the two plugs with which the ends of the tube are stopped up (and between which the filings lie) to a battery, the current will flow so long as the filings are cohering, but not when they are loose.

Now the difficulty that presented itself was that when once they had cohered the filings were loth to part again,

even when the ethereal waves had stopped. This, however, can be overcome by tapping the tube continually. Then the filings cohere only so long as the waves are arriving, and the moment they cease the filings fall apart.

So a little hammer, worked by a mechanism exactly like that of the ordinary electric bell, was employed to keep on tapping the tube, and it was worked by the current which passed through the tube as just described.

Thus, as soon as current passed owing to the filings cohering under the influence of the ether waves, a tap was given to the tube. If the train of waves was but short, and had ceased by the time the hammer had had time to respond to the current, then the tap shook the filings apart; but if it were longer, then the tap was unable to decohere the filings, and the apparatus went on tapping until the waves had ceased, and then instantly the hammer did its work. When we remember that wireless telegrams, like ordinary land telegrams, are communicated in the form of combinations of long and short signs (the well-known dots and dashes of Morse), it is clear how important it is that the received signal should be cut off at its correct length. If a dot were to be continued but a little, it would be indistinguishable from a dash, and so messages would become unintelligible. The importance of this little electric-bell apparatus will thus be made clear. And now I come to the point. It needed the genius of Sir Oliver Lodge to think of that simple contrivance, and even he left it for Marconi to get the full value out of it by careful arrangement and delicate adjustment. My friend, the eminent telegraph engineer, used to say that he considered the work of Marconi in simply arranging this simple

contrivance one of the best pieces of work that brilliant inventor had done. Depend upon it, the greatest inventions sometimes owe their success to the careful arrangement and adjustment of some apparently minor matter, like that, and it is in such small matters that the real genius becomes apparent.

It may appear that I have laboured this point, but I am anxious to help my readers to appreciate the merits of some of the great inventions which, judged from their apparent simplicity, could have been invented by anyone, whereas that quality is the very thing which proves their worth.

CHAPTER II

THE INVENTOR'S DRAWINGS

In the course of this book it will often be necessary to refer my readers to drawings and diagrams, for there are many interesting examples of invention which defy description by words only. The description needs to be reinforced by some pictorial representation of the object described.

Therefore, a short review of the methods by which mechanical matters are reduced to drawings will be useful. The ordinary perspective representation in many cases is useless. Therefore, the engineer draws the thing as if his eye were as large as the object itself, so that everything is the same distance away. There is then none of that diminution to the "vanishing point" which is the essence of the perspective drawing. Thus every part, whether near or distant, can be drawn to scale, and if the size is not figured on, it can be measured off the drawing. Sometimes a perspective sketch is called upon to give a general idea of a whole plant and to act as a key to the other drawings, but the scale drawings are never displaced by a perspective.

The engineer has certain terms for the different points of view. A drawing (like Fig. 7) showing the machine, or whatever it be, from above is a plan. To this architects sometimes add a "Plan looking up," which means the same thing seen from below; but engineers do not often need such a plan. Views from the front, end, or side

are called front elevation, end elevation, and so on. Then, most important of all, in many cases, is the "section," which reveals the inner and often the essential parts. The word section without any qualification generally means an imaginary view of how the thing

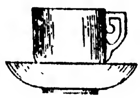
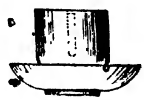
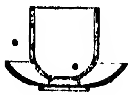




Fig. 2. Perspective. | Fig. 3. Side elevation. | Fig. 4. Front elevation.



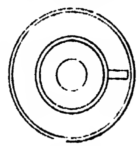


Fig. 5. Section. | Fig. 6. Saucer shown in section, cup shown whole. | Fig. 7. Plan.

Six views of a homely article, illustrating the different kinds of drawing.

would look if it were cut in two exactly through the centre and one half taken away. A longitudinal section assumes it to be cut through the centre "lengthwise"; a transverse or cross section supposes the line of division to run across. In complicated machines, or things of curious shape, there are often quite a large number of sections necessary in order to convey a clear idea of the thing represented. Then it is the practice to mark the place where it is supposed to be cut through on one of the other drawings (a plan, an elevation, or another section), by a thick dotted line with a letter at each end, such as A, B, or anything convenient. Then the section at that point is called "Section through A B."

The part which is cut through is always made darker

than the other parts. If the drawing be coloured, a darker shade of the colour which denotes the material is used for the part shown in section. For example, wrought iron is always shown blue. A piece of wrought iron shown as if cut through will, therefore, be a darker blue than the rest. In uncoloured drawings the parts in section are sometimes made quite black. At other times, or sometimes on the same drawing, such parts will be shown with light parallel lines across, "hatched" as it is called. When two parts are in contact, and are shown cut through, one is often hatched in one way, say from left to right, in a slanting direction, and the other from right to left, or one hatched and one black, while where there are three parts all three methods of indicating the section may be used.

A species of shading is often employed, to give brightness and clearness to a drawing, called "backlining." It is done by assuming that the light comes from one corner and showing all edges near that corner by a thin line and all those away from the corner by a thick line. It is marvellous how just a little thickening of a few lines will make things stand out clearly which before were flat and indistinct.

I have often heard people speak of a boy as being eminently suited to be a draughtsman because he can draw so well. They mean that he can produce certain sketches or drawings on paper, and they little think that that is the least of what a draughtsman has to do. He must not only be able to draw. He must know what to draw. Many a great firm owes its greatness to the clever brains in the drawing office, where men, often not too well paid, are constantly employed working out new ideas

or perfecting old ones, inventing new details which shall make the machinery on which the firm have made their reputation even better than it has ever been for its purpose, or else so that it can be made more cheaply. The draughtsmen are, in fact, a permanent staff of inventors always at work.

Drawings are made in pencil to commence with, and it used to be the custom to ink them in afterwards, and then junior draughtsmen would make duplicates of them by tracing the lines through on to some thin, semi-transparent paper or linen. During the last decade or so, however, photography has come into the field. Now a tracing is made in ink straight from the pencil drawing, and that tracing then becomes the "negative" off which any number of photographic prints can be taken. Sometimes a dozen, sometimes even hundreds of copies are needed off one drawing, and if it is at all complicated, tracing all that number is a long and costly matter, but prints can be taken off in a few minutes each at the cost of a few pence.

At first these were made in the sunlight just as photographs are made on P.O.P. A large printing frame was used into which the tracing was put with a piece of photographic paper behind it. Then it was placed in the light, and in a time, long or short according to the state of the sky, the print was finished. Then the photograph was taken out and washed to fix it.

In large works now the light of the sun is superseded by the light of the electric arc lamp, and the prints can then be turned out in rapid succession whatever may be the state of the weather. This itself has given rise to inventions of no little merit. One machine in particular there

is which can make a print a mile long if need be, and can be continuously at work from morning till night turning out prints all the time.

Imagine a glass cylinder about 20 inches in diameter and 4 feet high standing up vertically in a light iron frame. In the centre there hangs an arc lamp, while one-half the circumference of the cylinder is enclosed by a travelling blanket. This is really what its name signifies, a woollen cloth; it is doubled, and has its two ends sewn together. Then it is stretched between two rollers, so that when they are turned round it travels along, rubbing over the surface of the cylinder of glass. To one side there is a wooden roller on which is wound the tracing or "negative," while on another near by there is a length of photographic paper. The end of the tracing and the end of the photo paper are both taken to the place where the blanket touches the glass, and they are pushed in between it and the glass. Then the motion of the blanket carries both along, the one behind the other, past the light in the cylinder. Meanwhile the latter is continually going up and down throwing its light on the tracing and through it on to the paper. The length of the exposure is regulated by varying the speed at which the blanket moves.

Emerging at the other end of the half-circle the tracing and print are wound automatically upon two other rollers. And so the process goes on, print after print in rapid succession being made if need be. Indeed, the trouble in most places is that there is not enough work to keep the machine employed, and so it is standing idle a good part of its time. It is generally driven by a tiny electric motor.

The photographic paper used is generally what is known as ferro-prussiate paper. When it comes from the printing machine it only needs to be washed in water and dried, when it is finished and quite permanent. It gives white lines on a blue ground, hence such prints are often spoken of as "blue-prints." There are other papers which give dark lines on white, but they are more costly and need to be fixed with chemicals.

Then the draughtsman has of late years profited by another simple invention—the draughting machine as it is called. No one who has not pored over a drawing board lying flat upon a table or only slightly tilted can realize the fatiguing nature of the task. No change of position is practically possible, but the draughting machine enables the board to be set at any angle and any position which the draughtsman likes. It may be even quite vertical, and the man may work at it just as an artist does upon a canvas upon an easel, for his tools or instruments will not roll off. The simple T-square, which made the nearly level position essential in the old drawing board, gives place to a flat ruler, which is connected to some mechanism by which it must always be quite square with the edge of the board just as the old T-square was, but yet cannot fall off.

And now after this preliminary chapter, intended mainly to enable my readers to understand the drawings which I shall have to use subsequently, but into which I have slipped two interesting little inventions, we will pass on to another more or less preliminary chapter, describing some of the materials, as we might call them, on which the inventor works, existing inventions which he often has to adapt to modern needs.

CHAPTER III

FUNDAMENTAL INVENTIONS

THERE are certain mechanical devices which form the basis of nearly all modern inventions. They are themselves old, some of them so old that the story of their origin is entirely lost. Yet they are so much used now that to make the latter part of the book easily understandable I must devote this preliminary chapter to a discussion of them.

Probably every one of my readers has seen at some time or other, perhaps on the ironwork of a new building in course of erection, a man drilling a hole with the tool known as a "ratchet race." The worker generally sits or lies in the most comfortable position which circumstances will permit, and alternately pulls and pushes a handle. As the handle moves in one direction, either towards him or away from him, a clicking sound is heard, but while it goes the other way the clicking is silent. Now the essential part of that machine is a certain kind of tooth wheel, called a ratchet wheel, working in conjunction with another thing called a pawl. The ratchet wheel has teeth which all lean in one direction, and the pawl is so placed that its point fits right into the jaw-like opening between a pair of teeth. The illustration Fig. 8 will make this clear.

The value of the whole appliance lies in the fact that

the pawl prevents the wheel being turned in one direction, but allows it to turn freely the other way. Or, what is really the same thing, if the pawl be pushed in one direction it will push the wheel round, while if it be moved in the other direction it simply slides over the teeth without doing anything at all.

That is how it operates in the ratchet brace. The movement of the handle in one direction pushes the pawl so that it engages with one of the teeth and pushes the

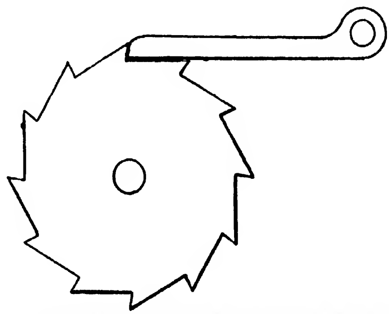
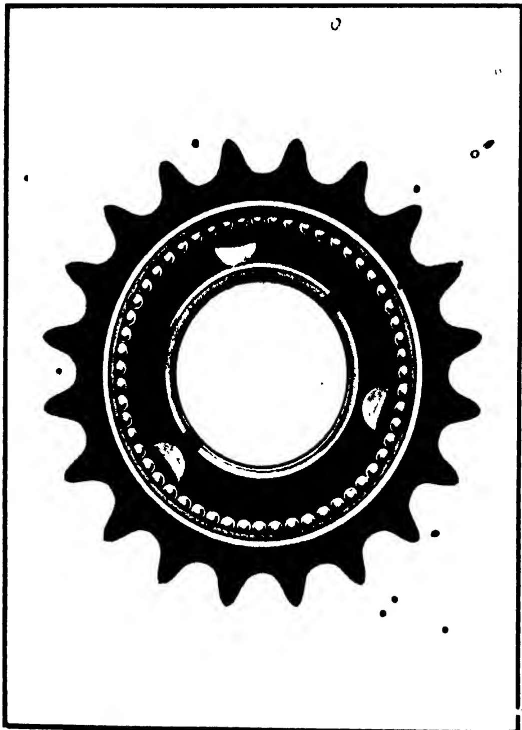


Fig. 8. This represents a ratchet wheel and pawl, a most useful form of mechanism.

wheel round; but when it is moved the other way the pawl simply slips over the teeth, producing the clicking sound mentioned just now. The drill is attached to the wheel, and so whenever the handle is moved in the direction which turns the wheel the drill is turned.

And that is but one example of the use of the ratchet and pawl. They are to be found in thousands of the inventions of to-day, one of the best known being the "free-wheel" arrangement on a bicycle. This consists simply of a very nicely made ratchet and pawl.

The purpose of nearly all these fundamental inventions



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A MUCH-USED INVENTION

This is the inside view of the well-known "free-wheel." The inmost ring is turned by the cranks. When moved in one direction the corners of the little half-round objects catch in the teeth of the outer ring and carry it round too, but when moving in the opposite direction they glide over without turning it.

is to convey motion from one place to another or to convert motion from one form to another, or else to change the direction or speed of motion. The ratchet and pawl is an example. In it we see a to-and-fro or reciprocating motion changed into a rotating motion of an intermittent kind. It is often necessary, however, to change a reciprocating motion into a continuous rotation. We see this in all engines except those of the turbine variety. The movement produced by the action of the steam or gas has to be changed into a simple rotation, and the mechanism employed is the connecting rod and crank. Every cyclist when on his machine illustrates this. His knees perform a reciprocating motion, but the lower parts of his legs, acting as connecting rods in connection with the cranks on his cycle, convert the up-and-down into the round-and-round motion.

It seems strange that such a simple idea as a connecting rod and crank can ever have been the subject of a patent, yet such is the case. When Watt first conceived the idea of using the steam engine, which up till then had been employed only in pumping water, for turning machinery he intended to use a connecting rod and crank to turn the up-and-down motion of his engine into a rotating movement, but someone forestalled him and patented the crank, so that Watt had to devise another and inferior mechanism, known as the "sun and planet motion," and use it until the other man's patent had run out.

The crank can be used, too, and often is used to turn a rotating motion into a reciprocating one. An example of this can be seen in many sewing machines, where the part which holds the needle derives its up-and-down

motion from the action of a crank and connecting rod. Those pumps, too, which are worked by turning a handle or wheel are nearly all examples of this use of a crank. In most steam engines the to-and-fro action, which is required to work the valves, is obtained by means of an eccentric. The result is exactly the same as it would be if a crank were used, but the eccentric is generally preferred, since it takes up less room on the shaft than a crank would do and is easier to fit. It consists of a circular disc which is fitted upon the shaft of the engine just as a pulley would be, only the hole through which the shaft passes is not in the centre. Instead, it is a little to one side, and so as the shaft turns the disc is given a motion which can best be described by the good old Anglo-Saxon word "wobble." The eccentric wobbles round and round, and being encircled by a ring or strap attached to the end of a rod, it imparts a motion to the rod similar to that which a crank would give it. An eccentric can turn rotating motion into reciprocating motion, but is never used the other way, since the friction would be excessive.

Sometimes a rotating motion needs to be conveyed from one place to another without change of direction, kind, or speed, and then a long, round rod is used called a shaft. It is simply a smooth, round bar supported at suitable intervals in what are called bearings in which it is free to turn round. The bearings generally consist of a drum of anti-friction metal, which encircles the shaft and which is itself supported in an iron block or pedestal. The anti-friction metal is something of the nature of brass and hence the drums are often spoken of as brasses. They are made in halves for convenience in taking the shaft

in and out. To prevent the shaft from moving along endwise, as it would probably tend to do, there are generally collars of steel fixed upon the shaft which slide against the ends of the brasses at one or two of the bearings and so prevent end movement. In the case of propeller shafts on steamers, and also in some forms of steam turbine, there is a great tendency for the shaft to move endwise, and there special bearings called "thrust" bearings have to be used. They are just the same in principle, however. There are several collars near together, and between them similar collars attached to the bearing so that the collars on the shaft slide against the collars on the bearing.

The shaft is generally turned at one end by means of a pulley fixed upon it, and the power is taken off it at other points from other pulleys. In a large factory it will often be noticed that the size of these pulleys is very various. That is because the shaft rotates at one constant speed, while the different machines may need to work at different speeds. A machine which works slowly will have upon it a large pulley and will be connected by a leather band or belt to a small pulley on the shaft. All parts of the belt will, of course, move at the same speed. That part which is passing round the small pulley will be going neither faster nor slower than that round the larger pulley, and since it is gripping, without appreciable slipping, the circumference of both pulleys, it follows that both pulleys must be moving at the same speed as far as the *circumference* is concerned. But, of course, the circumference of a pulley varies as the diameter, and so the larger the pulley the slower will it turn under these conditions. The circumference, for instance, of a 4-foot

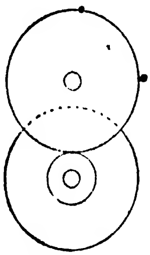
pulley will be twice as much as that of a 2-foot pulley, and so the same amount of circumferential movement will mean two revolutions in the smaller to one in the larger.

There is a well-known example of this in the small and large chain wheels on a cycle. When a machine is said to be "geared to 72," it means that one turn of the cranks is so increased by the action of the two chain wheels and the chain that it makes the back wheel, of perhaps 28 inches diameter, revolve more than once, sufficient, in fact, to be equal to one revolution of a 72-inch wheel. The result is exactly the same as if the cranks turned directly a 72-inch wheel.

Therefore the fast-running machines are driven by large pulleys on the shaft and the slow ones by small, the power being conveyed from the shaft to the machines by endless belts. This endless band is itself one of the most valuable of the fundamental inventions. It appears over and over again not only in the bicycle and on the driving shaft in the factory, but wherever a rotating motion is required to be changed into a straightforward motion always in the same direction. There are machines for conveying such things as coal which consist essentially of simply an endless band, while endless chains of buckets dredge out the mud from the docks and harbours, and endless ropes carry ore and other valuable products across miles of almost impassable country. The endless band in one form or another will often be seen by anyone interested in mechanism.

The band which connects two machines together works by friction. If the two pulleys which it connects were absolutely smooth and the band itself like them, the driving pulley would simply slip and neither the band

nor the driven pulley would be moved. In fact, however, there is a great deal of friction between the leather band and the metal or wood pulley, and so the one slips but little when in contact with the other, and the driving pulley moves the band and the band moves the driven pulley.



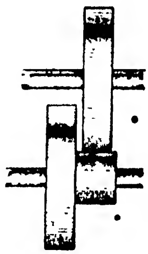


Fig. 9. Fig. 10.

Friction gear. These show how one wheel can drive another by friction.

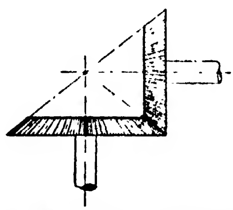


Fig. 11. This represents bevel gearing, in which one wheel turns another in *a different* direction altogether.

The same result can be obtained if the band be dispensed with and the two wheels be simply placed in contact with each other. Two metal wheels so used would tend to slip, but if one be made of wood or compressed paper or covered with a layer of leather they will work well with little slip. Such wheels constitute what is called friction gearing. By this means speeds can be changed readily, for a small wheel can be made

to drive a large one or vice versa. In another form the wheels are made with bevelled edges and then one wheel can drive another at right angles to it, or by varying the angle of the bevel the shafts may be at almost any angle. In some machines a wheel is made to drive by friction against a disc. That has the advantage that, by moving the wheel nearer to or farther from the centre of the disc the speed of the latter can be varied.

More often still, the wheels which thus have to work together are provided with teeth, so that they catch or engage with one another. That has the effect of preventing any possible slip between the two wheels so long as they are reasonably near their proper distance apart. In friction gear the two wheels must be pressed together with just the right amount of force, for if pressed too much there will be needless friction in the bearings, while if not enough they will not grip each other. The friction gear has this great advantage, however. It forms a kind of safety valve, which lets off the power if too much should be used. Lathes, for example, are sometimes driven by this kind of gear, and if the workman should attempt to do too much on the machine, try to take too thick a shaving off the object being turned, for example, all that will happen will be that the friction gear will slip. If tooth gear be used under those conditions something has got to break. Friction gear, too, runs more quietly and smoothly than tooth gear, and is much more convenient when the two wheels have to be brought together while one is in motion.

Small wheels in gearing are often called "pinions," especially when the small one is fixed to the side of the large one, as is often seen in clockwork. A combination

of a large wheel and a small one is called a wheel and pinion. In some machines a pinion is made to work in connection with a straight bar, on one edge of which teeth are formed. The straight bar is a "rack," and the two a rack and pinion.

There is a very useful little appliance, too, called a worm. It is simply a screw, and it is fixed in bearings so that it can rotate freely but cannot move endwise. Its thread is made to engage with the teeth of a tooth wheel, and so, as the worm is turned rapidly round the wheel is moved slowly. This "worm gearing" is often used in lifting appliances, such as electric lifts, where the motor turns the worm and so turns the wheel which winds in the rope to which the cage is attached. It has three great advantages; it can effect a very great reduction in speed, it is perfectly silent, and (unless the thread of the screw be very steep, or "fast," to use the technical term) whereas the worm can turn the wheel, the wheel cannot turn the worm. Therefore, in the example mentioned just now, the electric lift, the motor can easily raise the cage, but the weight of the cage cannot turn the motor and so the apparatus is "self-sustaining." If friction or tooth gear were employed, as soon as the current was turned off from the motor, the cage would, unless otherwise held, commence to run down of its own weight, driving the motor backwards.

I have no knowledge of the origin of this term "worm," but it is probably the happy invention of some obscure workman who noticed the curious wriggling appearance which it has when in motion, just like the action of a particularly vigorous worm, and so applied the name to it. The "happiness" of the appellation would, no

doubt, cause it to catch on, until it had become the recognized orthodox term. Many technical words have arisen in this way.

An excellent example of the use both of tooth gearing and of the endless band is provided in the ordinary lathe,

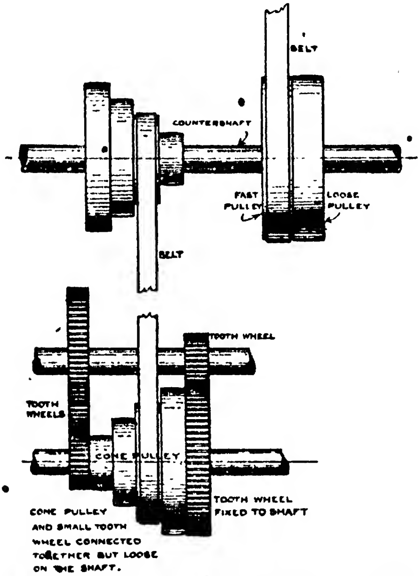


Fig. 12. A group of inventions. The "gear" for driving a lathe, which embodies at least four separate inventions, all of great importance.

perhaps the most familiar of all machines. For there are few people who have not at some time or other been in an engineer's shop and seen lathes at work there.

A prominent feature of every such machine is the cone pulley as it is called, for while everything else may be dark and dirty it is always bright. It is like a number of pulleys placed close together, in fact made into one solid

piece. It will be recognized at once from the illustration Fig. 12. Its purpose is to vary the speed of the lathe, a function which it performs in conjunction with a short shaft fixed often to the ceiling just above the machine. This countershaft, as it is termed, has a similar cone pulley fixed upon it near one end, and near the other end two pulleys the same size close together. A band of leather or cotton passes from the main shaft, which is driving all the machinery of the shop and which is itself driven by the engine, to one of the two pulleys. One of them is fast upon the shaft, so that when it turns the shaft is turned too, while the other is loose, so that it can rotate without turning the shaft. Normally the band is upon the loose pulley, but when the attendant wants to start his machine he guides the band off the loose pulley on to the fast one. This he does by means of a little appliance called "striking gear," provided for the purpose. An iron fork encloses the band, and the simple movement of a handle forcing this fork to one side or the other guides the band to either the fast or the loose pulley as may be required.

A second band runs from the cone pulley on the countershaft to that on the lathe itself. Now these two pulleys are fixed opposite ways. One has its small end to the right and the other has its small end to the left, so that whichever pair of "steps" the band may be on the total size of the two is the same, and so the band will fit any of them. Therefore it can be moved easily from one to another.

Now suppose the sizes are 6, 8, 10, and 12 inches. If we put the belt so that it connects the 12-inch "step" on the countershaft to the 6-inch step on the lathe, the

latter will be driven twice as fast as the countershaft, for 6 is half of 12. If, then, we shift it to the next step on each we get the 10-inch on the one driving the 8-inch on the other, with the result that the latter turns $1\frac{1}{4}$ times as fast as the former. Another shift and the 8-inch is driving the 10-inch, so that the latter pulley is going *slower* than the countershaft. Finally, if we let the 6-inch drive the 12-inch the lathe pulley will go only half as fast as the countershaft. Thus, by simply shifting the band from one part of the cone pulleys to another we can produce great variations in the speed, while by shifting the other band from the fast to the loose pulley, and vice versa, we can start and stop the machine.

Then, for turning hard metal, a high speed is not so much needed as great power. That accounts for the tooth wheel which we see at each end of the cone pulley. The latter is not itself fixed to the spindle upon which it turns. It is free to slide round easily. It is, however, connected rigidly to the *small* tooth wheel A, which is to be seen at the left-hand end of it. Therefore, when the cone pulley turns, the small tooth wheel turns too. That, as you will see by the illustration, revolves wheel B just behind it. That in turn operates tooth-wheel C, which is in gear with tooth wheel D. This looks as if it formed part of the cone pulley, but it is in fact not connected to it in any way. Instead, it is *fixed* to the spindle, on which, as I have just said, the cone pulley turns loosely, and on the end of which is fixed the part which actually holds the article being operated upon. Thus the simple arrangement of four tooth wheels reduces the speed at which the spindle of the lathe turns, and gives it such power that it can take a thick shaving off hard metal.

CHAPTER IV

THE CYLINDER AND PISTON

ONE of the most important of these basic inventions is certainly the cylinder and piston. It was first invented in connection with the pump long before the time of the steam engine, but it is as a part of the steam or gas engine that we most often meet with it.

It is seen in its simplest form in the suction pump, a section of which is submitted to the attention of most schoolboys under the guise of elementary science. It plays a most important part in nearly all those machines which are driven by the force of a fluid under pressure, such as steam engines and gas engines or the hydraulic lift, and in those other machines in which the reverse operation takes place, namely the pumps.

The cylinder of a steam engine (Fig. 13) is generally made of cast iron, the inside being turned or bored perfectly true and smooth. The piston is a flat iron disc, which nearly fits the bore of the cylinder but not quite, for if it did the friction between them would be too great. Yet there must be a close fit, if not a tight fit, between the two, or else the steam will escape past. The two requirements, namely freedom from friction and steam-tightness, are reconciled by the use of a system of spring rings. In the edge of the piston there are formed a number of grooves running right round it, and in these grooves

cast-iron rings are placed. The rings are perfectly smooth and just fit nicely in the grooves; moreover, they are not quite complete, but are severed at one point so that they can be sprung open a little to get them on the piston. Further, they are made a little larger than the piston, and, indeed, a little larger than the inside diameter of the cylinder, so that to get the piston into the cylinder the rings have to be pressed in a little. Once in, therefore, they tend to spring out again and so press lightly and

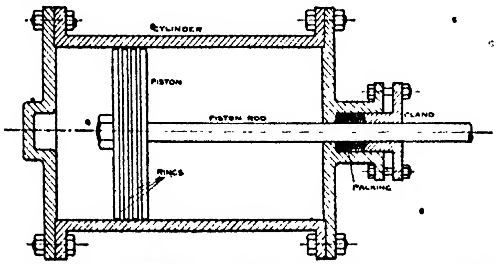


Fig. 13. The cylinder and piston of a steam engine, which illustrates in a general way the construction and working of all cylinders and pistons in engines, pumps, presses, and lifts.

evenly upon the sides of the cylinder, making a good steam-tight joint between the two, yet causing little or no friction. It may surprise some readers to hear that cast iron is generally used for these, for we are apt to think of cast iron as being brittle and far from suitable for anything which is of the nature of a spring. Really, however, even cast iron has a remarkable amount of elasticity.

The movement of a piston in a cylinder would naturally be of little or no use to us without some means of communicating it to the outside. The piston is, therefore, connected to a rod termed the piston rod, which passes

out through a hole in one of the covers which close the two ends of the cylinder. And here the same difficulty arises. If the rod be a tight fit in the hole there will be friction, while if it be loose steam will escape. To prevent both these things the hole in the cover through which the rod passes is surrounded, on the outside of the cylinder, with a socket a little larger than the rod. At the bottom of this socket and around the rod is placed some soft packing of cotton, hemp, or asbestos, and then, what may best be described as a short piece of pipe which just slides easily on the rod, is forced down into this socket so that it squeezes the packing against the rod. The force with which the "pipe" is pressed in can be varied so as to adjust the pressure of the packing against the rod until it just prevents the escape of steam and causes the minimum of friction.

In some modern engines the soft packing is replaced by rings of some soft metal, the reason being that the latter stands the high temperatures met with in modern engines better than the older kind of packing.

In a gas engine the cylinder is open at one end, so that there is no need for this "gland" as it is called. The piston in that case is not a disc, but a small cylinder itself. It has rings just as the steam piston has.

In "double-acting" pumps the cylinder is in principle much the same as that of a steam engine, but it generally has a chamber formed at each end to contain the valves, of which there must be two at each end, one to let the water in from the suction pipe and the other to let it out to the delivery pipe. In some cases the piston is very similar too. In single-acting pumps, however, the piston is simply the end of the piston rod

which is large enough to fill the cylinder very nearly. Such a piston can obviously act one way only, that is to say it sucks water in and forces it out again at one end of the cylinder only and not at both ends. The water is prevented from escaping by a gland through which the rod passes, or else by a specially formed leather ring.

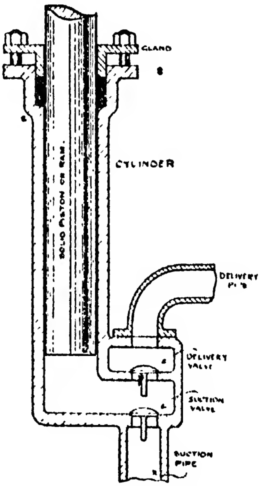


Fig. 14. The cylinder and piston of a single-acting pump. When the piston (or ram) ascends it sucks in water from the suction pipe; when it descends the valve prevents it returning the same way that it came, so the water is pushed out again through the other valve to the delivery pipe.

The same form of cylinder and piston is found, too, in machines which work by hydraulic pressure, such as hydraulic lifts, presses, and jacks. A piston of this description is more properly called a ram, and often the whole contrivance, piston and cylinder as well, are spoken of by that name. For example, when some heavy weight is said to be lifted by a hydraulic ram, it is a cylinder and

piston of this kind that is referred to. Some of them are of great length, such as those in the older type of hydraulic lift, where a well, as deep as the building is high, has been dug to accommodate the ram.

The principle upon which a piston works, it may be well to remind my readers, is this. If a fluid be admitted into a cylinder at a pressure of, say, 100 lbs. per square inch, it will exert 100 lbs. of force on every square inch of area which the piston possesses. For example, a piston 5 inches in diameter has an area of roughly 20 square inches, and steam at 100 lbs. pressure would therefore push a piston of that size with a force of 2000 lbs. The same principle applies for any size of piston, and any pressure per square inch. The latter multiplied by the former will always give us the total force exerted.

And the reverse is equally true. In the case of the cylinder of a force pump, the pressure per square inch which the pump is able to impart to the water is the total force exerted, divided equally over the number of square inches in the area of the ram. For this reason, when a steam pump is used to feed the water into a boiler, the water cylinder always has to be a little less in diameter than the steam cylinder. For, suppose the pressure in the boiler were 150 lbs. per square inch and the area of both the piston and the ram were 4 inches, the steam would press with a force of 150 lbs. on every square inch of the one, and the water, since it is in communication with the boiler also, would press with a force of 150 lbs. upon the other. The two forces, being equal and opposed, would thus balance and nothing would happen. If, however, we make the steam piston 6 inches in area, then the steam will push it with a force of 900 lbs., while

the water will be resisting it to the extent of only 600 lbs., with the result that the resistance of the water will be overcome and it will be pushed into the boiler.

Before concluding this chapter one must refer to the valves, which play such an important part in all machines where fluids, either liquid or gaseous, have to be controlled.

The ordinary tap on a gas fitting is a simple valve; in fact, the only difference between a tap and a valve is that the former word is generally used to signify small things, while the latter is applied to larger ones. A well-known type of valve, which is used to control the flow of steam into and out of the cylinder of certain high-class steam engines, the Corliss valve, to wit, is really only a gas-fitting tap greatly magnified. A metal plug normally stops up a pipe. It has a hole or passage through it, however, which, when the plug is turned into a certain position, forms a continuation of the pipe and allows the fluid to pass through.

Large valves are, however, seldom made on that principle. In some of them the passage of the fluid is stopped by a "gate" which slides up and down in a little chamber formed for it in the body of the valve itself. It is raised and lowered by a screw, so that when it is up there is a full, uninterrupted way for the fluid to flow through, while when it is down the passage is entirely closed. These are known as "gate" valves.

The water taps used for domestic purposes illustrate another type, which are also worked by a screw, but the arrangement is a little different. The bulb-like part of the tap, where the "works" are, consists of a little chamber divided horizontally by a floor in the centre

of which there is a hole. The water from the cistern enters above this floor, passes down through the hole into the lower part, and then away through the spout. When you turn the tap off, what you do is to screw down on to this hole a cover which entirely closes it and so stops the flow of water.

The passage of steam from a boiler to the engine is controlled by a governor which closes the passage a little if the engine should go too fast. This requires a very delicate valve which will readily work with very small power. Such a valve is found in the type known as "butterfly valves." It consists of a disc which exactly fills the bore of the short pipe which forms the body of the valve. It is mounted on a spindle which can be turned so that a quarter of a turn of the spindle will turn the disc from square across the pipe, entirely stopping the flow, to an edgewise position which allows almost a free passage. It is called "butterfly" because the two halves of the disc, one on each side of the spindle, are something like the wings of a butterfly, the spindle forming the insect's body. Because of its purpose, which is to throttle the passage of the steam, such are often called throttle valves as well.

When a valve is used to control a liquid at heavy pressure, the force is often such as to press the part which is obstructing its passage heavily upon its seating, the part, that is, against which it rests. This makes it very difficult to work, and then an "equilibrium valve" is often used. The essential feature of this is generally two pistons upon one rod. These can move up and down inside a cylinder. The steam, or whatever it is, enters at the side of the cylinder near the bottom, while the outlet

is also on the side higher up. In the open position both inlet and outlet are between the pistons, and then the steam enters, passes a little upwards, and out again. If the pistons be pushed down a little, however, the upper piston comes between the inlet and outlet and the steam is stopped. Now, at first sight, it seems as if that would be a hard valve to work, for the whole force of the steam appears to be pushing the upper piston upwards, and to close it the piston would have to be driven downwards against this enormous force. Quite true; but however energetically the steam may be pressing the upper piston upwards, it is equally pressing the lower piston downwards, so that the force required to move the pair is very little. In fact, since the steam is always between the pistons, it never has a chance to force the moving part of the valve against any fixed part. All it does is to try and force the two pistons apart, which the rod between them is quite easily able to resist. For this reason the value of such valves for controlling steam at high pressure will be apparent, and, as we shall see presently, their use in certain types of steam engine is the source of considerable economy.

The purpose of the non-return valve has been referred to already. It is also called the back-pressure valve, since it prevents a fluid which has once been forced through it from pressing back again. It has many forms. Sometimes a hole or a number of holes, covered with a piece of leather held by one edge only so that it can flap up and down, answers the purpose admirably. Or it may be held by the centre so that the edges are free. A hinged flap is another form often used, while the best of all, perhaps, is a metal ball. The hole through which the

fluid enters the valve terminates in a hollow or cup in which the ball lies. When the fluid enters, it lifts the ball and passes in freely, but as soon as it attempts to return the ball falls into the hollow and is forced down on to the mouth of the hole, thereby sealing it up most effectually. There is generally a little cage, or something of that sort, to prevent the ball from being lifted right away from its seat. It is allowed to move far enough to give a clear path for the fluid, but not too far to return quickly and with certainty to its seat as soon as it is needed.

CHAPTER V

THE BASIS OF MANY INVENTIONS

THE most important of the inventions of modern times are based upon the use of heat. Their object is to convert heat into work; and to be able to understand them we shall need to consider for a moment some of the ways and peculiarities of this wonderful property.

No one works a machine by hand if by any chance he can get some power to do it for him, and in the vast majority of cases the power is derived directly from heat. The steam and the gas engine are alike heat engines, while the waterwheel and the windmill derive their power from the same source, but less directly. The tide-motor is the only instance of power being generated apart from heat, and that is so little used as to be almost negligible.

It is possible that some readers may be tempted to dispute this statement on the ground that a chemical battery such as is used for electric bells and telegraphs is not worked by heat; yet it is quite correct. The essential part of such a battery is a rod or plate of pure zinc, which is eaten away by acid as the battery works. Such metal is not found in a pure state in nature, but only in the form of ore, in combination with some other substance, and heat has to be employed to separate the metal from the other substance. Therefore the chemical battery cannot work without heat. The fact is that heat has to be used

to divorce the zinc from its associate in the ore, while in the battery the two come together again, giving back, in the form of electricity, the heat which was used to separate them. Thus there is quite a direct relation between the action of the heat in the furnace and the chemical action in the battery.

Over a century ago James Watt taught the world how to use heat to generate power. He found the "atmospheric" engine a crude, clumsy machine, only suitable for one purpose, pumping water, and he turned it into the steam engine not much different from the steam engine of the present day. Since his time there has been constant improvement, though nothing to compare with the great advance which the heat engine made in his hands. Yet still it is most wasteful, for its function is to change the power for work latent in coal into active power of which we can make use, and it loses at least 85 per cent of it in the process.

At first sight this seems to be but a fanciful conjecture, or at any rate only a rough approximation, for who can tell the amount of work stored in coal? Coal can, we know, when burnt, generate heat; but that is not power, and to state that a certain amount of heat is equal to a certain amount of power is comparing, so it seems, two things which are not comparable. It appears about as reasonable as to say that a gallon of water is equal to half an hour, or some nonsensical statement like that.

It is a fact, however, that we can gauge very accurately the value of the heat in coal, and tell what amount of work an ideally perfect engine would get out of it.

To see how this is done we must, first of all, see how to measure quantities of heat. The thermometer will not

do this, for it tells us only what we might term the "level" of the heat in a certain substance. It does not tell us the quantity of heat which the substance contains. The level or height of water in a vessel does not by itself tell us the quantity of water in that vessel. If, however, we take a properly made vessel of a standard size and fill it up to a certain point, we know that we have got 1 gallon; and in the same way, if we take a certain standard substance and fill it with heat up to a certain "height," then we obtain a measure which expresses quantity of heat just as the gallon expresses quantity of water.

The substance which we use is *one pound of water*, and the quantity of heat which raises its temperature one degree Fahrenheit is the measure of heat-quantity or the thermal unit.

That this thermal or heat unit is quite different from the temperature is shown by the fact that we can use one unit to raise half a pound of water two degrees, or two pounds of water half a degree and so on.

Now, if we take a certain quantity of any fuel and make it up into a cartridge, with sufficient oxygen for it to be completely burned, we can burn it in a vessel under water, so that all the heat generated will pass into the water. A thermometer will tell us by how many degrees the temperature of the water is raised, and, knowing the quantity of water, we can easily calculate from that how many units of heat were evolved by the burning of that quantity of fuel. Thus we are able, experimentally, to determine the number of heat units per pound in different fuels. This is usually termed the calorific value of the fuel. For wood it is about 7000. For coal it varies according to the quality, but 14,700 is about the average.

We see, therefore, that we can measure the quantity of heat stored in fuel. Now we will see how to measure work, and then, if we can find some connecting link between the two, we shall be able to tell precisely what proportion of the heat energy of the coal becomes converted into mechanical energy in an engine.

In the early stages of his investigations into the use of the steam engine, Watt became conscious of the need

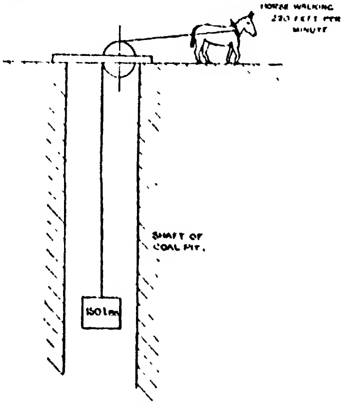


Fig. 15. This shows how Watt found the value of a horse-power.

for some measure by which he could state the rate at which an engine did work. The power of the horse struck him as being a convenient standard, so he made experiments to find out what a good strong horse could do. He fixed up a pulley over the mouth of the shaft of a coal pit and passed a rope over it, with a weight of 150 lbs. on one end. The other end he attached to a horse so that when it walked it pulled the weight up out of the pit. He found that the horse could lift the weight at the rate of 220 feet per minute. Now, 220 multiplied by 150

comes to 33,000, and so the "horse-power," the unit by which the working power of engines is now measured, is 33,000 foot-pounds per minute.

The term horse-power, then, is a unit for expressing the rate at which an engine does work, and the unit of work is the foot-pound or the work done in lifting a pound 1 foot high. This, of course, does not simply mean a single pound a single foot, but is equally applicable to any quantity of either. For example, 2 lbs. lifted a foot high would be 2 foot-pounds; 5 lbs. 6 feet high would be 30 foot-pounds, and so on. In short, the multiplication of the number of pounds which it lifts by the number of feet through which it lifts them in a minute gives us an accurate means of estimating the work done by any engine. And if an engine is capable of doing 33,000 foot-pounds of work in a minute, it is said to be of 1 horse-power. If it does 330,000 foot-pounds in a *minute*, it is doing work at the rate of 10 horse-power, and so on.

The next thing that we need is the connecting link. We give the engine heat; it gives us in return work. To know how well or badly it is doing its duty we must find how many heat units are equal to a foot-pound. That is called the "mechanical equivalent of heat."

The "mechanical equivalent" was first determined by Dr. Joule, of Manchester, about the middle of the nineteenth century. It was the result of a number of experiments, one of which will suffice to make the idea clear.

He arranged a cylindrical vessel of water, with a vertical shaft in the middle, and attached to the shaft a series of arms or paddles. Fixed to the top of the shaft was a drum, around which a cord was wound, and

the end of the cord was taken over a pulley so that its loose end hung down vertically and supported a weight. The effect of the weight was to pull the cord, thereby turning the shaft, and violently agitating the water. In other words, the water tended to resist the movement of the paddles and the rotation of the shaft; and the energy used in turning the shaft against this resistance would therefore be turned into heat at the point of resistance,

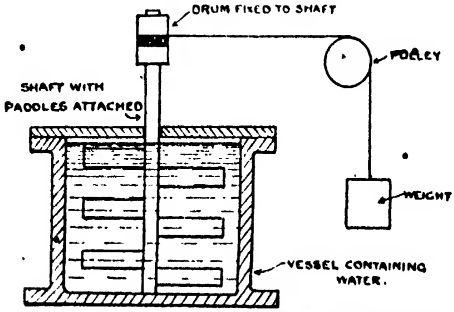


Fig. 16. This shows the principle of the apparatus by which Dr. Joule discovered the "mechanical equivalent."

namely, in the water. This generation of heat always occurs when work is done against resistance, as when we rub out a pencil mark with indiarubber and the rubber and paper become heated, the mechanical energy used being converted into heat. The mechanical energy of the falling weight was therefore converted into heat in the water. Now, the experimenter knew the amount of mechanical power used, for he knew the number of pounds in his weight and how far it fell. By means of a delicate thermometer he was able to tell the rise in the temperature of the water; and knowing the quantity of water in his apparatus, he was able to calculate from that the

number of heat units developed in the water by the falling of the weight. He knew, of course, that a certain amount of heat must have escaped, and that a certain amount of mechanical energy was left in the weight, too, when it struck the ground, owing to its momentum; but he was able to make correct allowances for these and to determine that it took 772 foot-pounds of mechanical energy to produce a unit of heat. To put it plainly, 1 heat unit equals 772 mechanical units or foot-pounds, or, according to later computations, 778.

Of course, this experiment works the opposite way to the heat engines which we are discussing. They convert heat into work, while Dr. Joule's apparatus converted work into heat. Still, unless our fundamental ideas as to the constitution of the universe are all wrong, what is true one way must be true the other, and if a unit of work is equal to $\frac{1}{778}$ of a unit of heat, then a unit of heat must be equal to 778 units of work, even if we cannot find a satisfactory way of converting the heat into work.

Therefore, for every pound of coal which is burnt under the boilers of a steam engine, we ought to get back an amount of work which we can calculate by simply multiplying the calorific value by the mechanical equivalent.

In a technical table-book of repute recently published, it is stated that the average consumption of coal in a good compound condensing engine is 2 lbs. per horse-power per hour. The heat units in the 2 lbs. of average coal should give 22,873,200 foot-pounds of work according to our theories. A horse-power for an hour is, of course, 33,000 foot-pounds. multiplied by 60, which equals 1,980,000. Put briefly, then, this average high-class engine scores 2,000,000 out of a "highest possible"

of 22,000,000. The percentage works out at about 9 per cent.

Now, the idea that the power of the engine is due to the actual conversion of the heat into power is not mere theory. It can be actually seen in practice. If two vessels be connected by a pipe, but temporarily separated by means of a tap, one can be filled with steam, while a vacuum can be created in the other. Then if the tap be opened the steam will expand until both vessels are filled equally. There will still be the same quantity of steam in the apparatus, only it will be thinner—more attenuated. The temperature will have fallen also, for the same quantity of heat which was contained in the one vessel will be distributed between the two. Unless, however, some has escaped through the walls of the vessel, *there will still be the same amount of heat in the apparatus.* If, however, on its way from the steam vessel to the vacuum vessel we make the steam do work, drive a small turbine, for instance, or push a piston, we shall find that heat will disappear somewhere. The total quantity of heat in the apparatus will be diminished, and we shall not be able to account for it by supposing it to have escaped. Heat will simply have GONE. Where, then, can it have gone to? It has been converted into power. The work done by the turbine or the piston will be found, if measured, to account exactly for the otherwise mysterious disappearance of the heat.

Now, the loss of 85 per cent or more of the energy of the coal in the process of conversion is so striking that many men have very naturally sought to discover means by which steam engines could be improved or else replaced by some less wasteful device for the same purpose.

Hence we have many important inventions in both these directions.

As a matter of fact, however, a very large part of that loss is entirely inevitable in any heat engine. The whole reasoning by which this is proved is too complex for repetition here, but it will be enough to say that it is due to the fact that we live in the midst of an ocean of heat, so that the amount of heat which we can generate in one place and set to work is only a small proportion of the total heat which we have to deal with.

The zero of the thermometer does not denote the entire absence of heat. In the Centigrade scale it signifies freezing point, while in the Fahrenheit scale it is but 32 degrees below, and we are able without much difficulty to produce much lower temperatures than those. We are forced to indicate them by using the numbers of degrees backwardsway when they pass the zero point, and putting the algebraic sign for minus in front of them. We cannot, however, by any means known to man, get down to the real zero, the point, that is, where there is no heat at all. That point, however, can be determined theoretically, and it is useful in many calculations, among them the one we are now concerned with. It is called the "absolute zero."

If a thermometer be made of a plain glass tube, without any bulb and filled with air instead of the usual mercury, we have a very delicate and sensitive thermometer. In such a case we must have a little pellet of mercury in the tube to act as a piston and indicate the expansion and contraction of the air. Now, if such a thermometer be made so that the column of air is 37·3 inches high when at the boiling point of water, or 100 degrees (using the

Centigrade scale for a moment), and we then cool the apparatus down to freezing point, which is 0 degrees, the pellet of mercury will fall just 10 inches or $\frac{1}{10}$ of an inch for every degree. From that we can reason that, could we go on making the apparatus colder and colder indefinitely, the air would contract $\frac{1}{10}$ of an inch for every degree of cold, a process which would apparently only end when the temperature of *minus* 273 degrees Centigrade was reached. We may never be able to reach[1] such a terrible degree of cold as that except in imagination, but the theoretical zero which we are thus able to determine is useful. Its equivalent on the Fahrenheit scale is minus 460.

Now it must be understood that we are only able to make heat do work when we have a difference of temperature. Water will not flow from one tank to another at the same level, but if the water-level in one is lower than that in the other it will flow voluntarily, indeed it will flow with such energy that we can make it do work on its way. In a similar way heat will not flow from one body to another unless the second one be colder than the first.

Thus, if we use heat to expand water into steam as in the steam engine, or to expand certain gases, as in the internal combustion engines, we can make the expansion do work. The act of doing work will, as already explained, cause the disappearance of heat, and so the gas or steam will become colder and colder until it reaches the temperature of its surroundings, after which it will do no more work. The work which we can obtain is thus limited on the one hand by the highest tempera-

[1] It has been very nearly reached, by the evaporation of Liquid Hydrogen.

ture which we can obtain, and on the other by the lowest of which we can make use.

I have before me at this moment some particulars of a new and large generating station, belonging to a Government department, designed by some of the best experts and carried out regardless of first-cost, so that we may fairly regard it as the best thing of its kind that can be produced at the moment. In this case the steam enters the engine (a turbine) at a temperature of 550 degrees. It passes from the turbine to a condenser at a temperature of about 100 degrees, and it is that difference between 550 and 100 which enables it to do work. We will call that difference the "available temperature," since it is the temperature which is available to do work.

Now the highest possible efficiency of that plant (judged from a purely theoretical standpoint and ignoring for the moment all those imperfections which occur in even the best made machines in actual practice) is the proportion which the available temperature bears to the total temperature concerned, that is to say, the 550 degrees reckoned from the absolute zero. The available temperature is 550 less 100 degrees; the total temperature concerned in the transaction is 550 plus 460 or 1010 degrees. Therefore the proportion of 450 to 1010 represents the highest possible efficiency which could be attained (even if theoretically perfect) in an absolutely up-to-date steam plant, and it will be seen at a glance that as 450 is less than half 1010 it is less than 50 per cent. To be precise it is 45 per cent.

And here I am going to put in a word for the usefulness of mathematics, a much abused because little understood subject. Many a schoolboy wonders why he is afflicted

with it, and not a few fathers have thought that their sons might be better employed in learning something else. Beyond being able to add, multiply, and do the other simple forms of arithmetic, there is an idea that mathematics is but a useless form of mental gymnastics. Moreover, from the fact that it is necessarily introduced by arithmetic, which is to some people a most abhorrent subject, it is thought to be abhorrent throughout.

Now, as a matter of fact, arithmetic is but the mechanism of mathematics, and its more unpleasant forms, such as long addition, trouble the commercial man far more than they do the engineer. Some of the greatest mathematicians, indeed, have been poor hands at arithmetic. So it is not so unpleasant as it at first appears to be. And its usefulness becomes more and more apparent the more one knows of it.

The statement which I made just now as to the efficiency of a certain high-class steam turbine is understandable in a way, but its true meaning and the inferences to be drawn from it are ever so much clearer when expressed in mathematical form, and so they will furnish a simple illustration of the use of mathematics.

What is the proportion of one to two? The former is one-half the latter. Mathematically we express it by putting the first figure over the second in the form of a fraction, thus $\frac{1}{2}$. In the same way we can express the proportion between the available temperature and the total temperature by a fraction: $\frac{550 \text{ less } 100}{550 \text{ plus } 460}$, or it will be simpler still if we state all the temperatures in the number of degrees above the absolute zero. Then we get this fraction: $\frac{1010 \text{ less } 560}{1010}$.

Now that fraction represents the proportion between

the available temperature and the total temperature, or, in other words, the maximum efficiency of the turbine we are talking about. And if we can so change the figures in the fraction that we can make the value of the fraction greater we shall find a way of making a better engine. Let us see what we can do.

Evidently the best thing to do would be to reduce the 560, for if we could entirely get rid of that we should get $\frac{1010}{1010}$, which is the highest possible value for the fraction, and then our engine would have an efficiency of 100 per cent.

But that we cannot do because of the nature of steam. As we shall see in a subsequent chapter, the temperature at which steam collapses into water depends upon the pressure. At no pressure at all (not even the normal pressure due to the atmosphere) it condenses when it reaches about 100 degrees. At 100 degrees Fahrenheit, then, it "goes on strike," as it were, and refuses to do any more useful work. Therefore we cannot reduce the 560.

Nor can we reduce the 1010 with advantage, for the numerator of our fraction is less than the denominator, and if in those circumstances we reduce both equally we reduce the fraction. We can see this in a simple way, for if we take 1 from both numerator and denominator in, say, $\frac{2}{3}$, we get $\frac{1}{2}$, which we know is less. It is the same with any other fraction, and so if we reduce the 1010 we shall only make things worse.

Can we do any good by increasing the 1010? Yes, we can, for in just the same way, by adding 1 to each of the two figures which form the fraction $\frac{2}{3}$ we make it into $\frac{3}{4}$, which is of higher value, and so any increase in the

1010, although the same increase has to go on both the numerator and the denominator, will improve our engine, for it will increase the value of the fraction.

Now what I have just explained has taken time to set forth, but to anyone who is but slightly accustomed to handling figures like this, all that I have said is almost self-apparent the moment the state of affairs is put into the mathematical form.

The result of our investigations, then, is that the only way to improve the theoretical efficiency of the steam turbine mentioned is to increase the highest temperature, or, in other words, the temperature at which steam is fed into the engine from the boiler. And there practical difficulties present themselves, which, at the moment at any rate, are insuperable.

It is interesting to speculate, for a moment, on the different state of things that would exist if our normal temperature were much lower than it is. For instance, if we lived habitually at, say *minus* 300 degrees (or it is handier to call it 186 degrees above absolute zero, or 186 degrees (absolute)), the problem of the heat engine would be very much simpler. There would be no water at such a temperature, only ice. Nor would there be any air, as we know it, but it would probably be liquid and might play much the same part in our lives as water does now. It boils at about 186 degrees (absolute), just as water does at 212, and, no doubt, we should be able to use it for driving engines. When it boils it gives off vapour (which is air really) just as water gives off steam when it boils.

Now supposing that we were able, under such strange conditions, to make a fire at all, we could put some liquid air in a boiler and turn it into vaporous air just as we can

turn water into steam and use it to drive our engine. Suppose that our fire was able to provide the engine with air at 636 degrees (absolute), and that we were able to condense it at 186, then we should have the same available temperature as we had in the steam turbine referred to just now. The highest possible efficiency would, however, be very different. Expressed mathematically, it would be like this, $\frac{636 \text{ less } 186}{636}$, which works out at nearly 75 per cent, instead of the 45 which we are able to get from the same available temperature under the ordinary terrestrial conditions.

We may say, then, that at the moment the best possible steam engine, even though it were theoretically perfect, as we know it cannot possibly be, could not get 50 per cent of the value of the coal used and turn it into work. Still, between the 45 per cent and the 10 per cent or so which engines actually accomplish, there is a huge gap with plenty of scope for inventive power. How this preventible loss is being tackled, both in the steam engine and the gas engine, we shall see in subsequent chapters.

CHAPTER VI

INVENTIONS IN THE COLLIERY

COAL is the foundation of all modern industry. Where coal is, there the factories spring up; where it is not, the land is given over to cultivation, or is left unused. No country which does not possess an ample supply of coal can hope for eminence as a manufacturing community. Some few countries, it is true, have water power which, to a certain extent, takes the place of coal, and there is the possibility that in the future we may discover some other way of generating heat and power, but that seems to be far off—there is no practicable proposal in sight at present—and so for many years to come coal is likely to be one of the most valuable and needful of the products of the earth.

And, unfortunately, it is as hard to get as it is desirable. For it lies deep down underground—there is a coal pit in Lancashire nearly 3500 feet deep—and the men who get it have to work in the dim light of candles or of safety lamps. They have to labour, too, in the heated and impure atmosphere of remote workings, sometimes miles from the shaft and therefore from communication with the open air. In thin seams they have not room to stand upright, but must be continually in a stooping position, and when to these discomforts we add the risks due to occasional explosions in the mines, and the still greater

risks of individual accidents from falls of material from the roof of the workings, we must feel that the coal-miner's lot is not altogether an attractive one.

The inventions which have been made in connection with collieries are therefore of two kinds. Those which enable the coal to be broken, brought to the surface, and disposed of expeditiously when it has arrived there, and those which have for their object the prevention of accidents and the improving of the lot of the miner.

In order to make clear the purpose and meaning of most of these inventions, it is necessary, briefly, to explain the construction and working of a coal pit. To commence with, the coal lies in a bed or seam, sometimes, as in South Staffordshire, as much as 33 feet thick, but in other cases only a few inches thick.[1] Sometimes the seam lies in a horizontal position; at other times it is at a steep angle. Occasionally it "crops out" in the side of a hill, and then it may be got at by means of a drift or tunnel driven into the side of the hill, in which case the tunnel is generally driven downwards at a slight incline, and rails are laid in it along which trucks may be drawn. The empty trucks run down by their own weight, while the full ones are hauled out by an engine. In most cases, however, the seam is tapped by means of vertical shafts which are dug down from the surface. These shafts are lined with timber, brickwork, or iron plates. There are generally two of them, one known as the downcast and the other as the upcast shaft, the reason there are two being mainly to facilitate the ventilation of the underground mine. The top of the upcast shaft is generally covered over and a large

[1] Seams under a foot thick can sometimes be worked profitably.

fan is made to draw air out of it. The only way the air can get in is by passing down the downcast shaft and through the workings to the upcast, so the fan keeps up a continual current of fresh air throughout the mine. In order to convey the colliers to and from their work, and also to bring up the coal, there is a powerful steam engine on the surface which raises and lowers two iron cages in the downcast shaft. The term cage, unlike many technical terms, is really a very good description of the thing which it represents, for the colliery cage is a large framework built up of steel really worthy of this name, as will be seen from our illustration. In some cases these cages are so large as to have three floors or decks, one above another, and on each of these there are laid rails on which small trucks, generally called corves, can be run. At the top of the pit is a large framework, called the pithead frame, sometimes of wood, and sometimes of steel, supporting two very large iron pulleys, over each of which there runs a rope. One end of each rope is attached to a large steel drum which the engine turns, while at the other end is suspended a cage, and it is so arranged that as one cage is descending the other is ascending; when one is at the top, the other is at the bottom, and they pass exactly in the middle. It is more convenient, of course, for the men working on the surface that the cages should not arrive and need to be unloaded and reloaded simultaneously, but the principal reason for this arrangement is that the two cages balance each other, and consequently the only work that the engine has to do is to raise the load on the ascending cage. If the cages were left loose, of course, they would be apt to swing about in the shaft and knock against

the sides or against each other, so they always have guides of some description. Sometimes these are of timber fixed to the side of the shaft, in other cases steel rails are used, while in others still there are vertical wire ropes stretching from the pithead frame down to the bottom of the shaft. These are kept taut by having heavy weights fastened to their ends, and there are clips on the cages which grasp the guides and so the cages are guided up and down.

The arrangement at the bottom of the shaft depends largely upon the nature of the seam. But we will assume one in which the coal lies in all directions and fairly level. When this is the case there are from the bottom of the shaft a number of tunnels radiating in various directions. These are carried some considerable distance before the workings commence, the reason being that if the coal were dug away right at the foot of the shaft there would be nothing to support the earth around the shaft, and the shaft itself would probably collapse. Therefore this huge block of coal, often as much as 100 acres in extent, is left at the foot of the shaft, pierced only by these tunnels, which are made as small as possible. After they have proceeded to a safe distance, however, branch tunnels are constructed, branching off in various directions, somewhat as indicated by the plan in diagram Fig. 17, and at this point the working of the coal begins. To the right and left, at the ends of these branch roads as they are called, another tunnel is made, so we may picture to ourselves a long tunnel joining the ends of all these roads, and the wall of this tunnel farthest from the shaft constitutes the "face" of the coal. The miners work in small gangs, each gang

being allotted a certain length of "face" to work at, this length being known as a "stall." Some of the men break the coal down while others load it into corves, which run on temporary rails. These, when loaded, are pushed to the nearest main road, where they are made up into trains and hauled sometimes by horses, but often by mechanical means, to the foot of the shaft. The roof of the workings, that is to say the earth above the miners' heads, has to be supported while they work, and this is

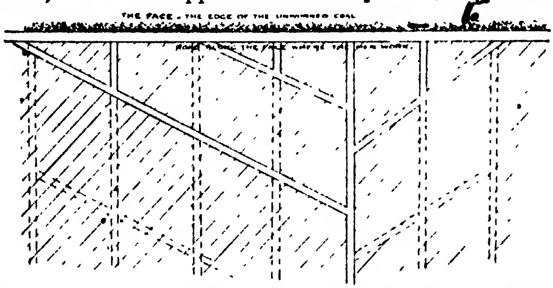


Fig. 17. Typical plan of a portion of a coal mine worked on the "Long-wall" method. The black part represents coal, the hatched part the "goaf" or old workings from which the coal has been taken, and which have been allowed to fall in. "Roads" are maintained through the goaf to enable the men to get to their work and the coal to be taken away. Dotted lines represent roads which have served their purpose and been allowed to fall in.

done by means of temporary timbering, vertical wood props with beams across them. It is not necessary, however, to keep the whole mine supported in this way, it is quite sufficient if a space is kept clear just by the face of the coal. As the coal is dug away and the face recedes farther and farther away from the foot of the shaft, fresh timbering is put up, the old removed, and the roof allowed to settle down. This, in time, causes the land above the mine to sink also, a source of great trouble when there are buildings upon it.

That is a brief review of the arrangement of a coal mine, somewhat ideal, of course, and not applicable in every case, because, as I remarked just now, the arrangements depend so largely on the natural circumstances of each mine, but what has been said will enable us to understand the working of the various contrivances which I am about to describe.

One naturally thinks first of the sinking of the shaft, which is, of necessity, the first operation in constructing a coal mine. This is sometimes a very simple operation. If the strata which have to be penetrated are soft and dry the material is simply dug away, and the lining of the shaft, whatever it is to be, is built round it. There are often, however, one or more strata of rock, and when such is the case it has to be blasted through. That difficulty is not hard to overcome, it simply means more labour. Quite different is the case where a stratum of wet sand is encountered. There great ingenuity and skill are called for, for although in some cases the water can be pumped out and the strata made dry, that is often quite impossible, for as fast as the water is pumped away other water soaks through from the surface, and so the supply is practically inexhaustible. Moreover, the sand itself flows almost as if it were water.

Of recent years a remarkable system has been invented for dealing with troubles of this kind. It is possible, of course, to sink small shafts, or bore-holes as they are more often called, a few inches in diameter, through *anything*, for the work can be all done from the surface. These holes are bored on much the same principle as a carpenter bores a hole in a piece of wood with an auger. The tool itself, which may be of a variety of forms to

suit the particular stratum which is being worked upon, is fixed to the end of a rod and the rod is turned round and round, or else jumped up and down, by any suitable mechanical means. In some cases both movements are carried on at the same time. As the tool cuts its way down through the earth additional lengths of rod are screwed on. Even hard rock can be penetrated in this way, the tool in that case being provided with a ring of diamonds which will cut through the hardest substance known, while the water-logged stratum presents no difficulties at all for this method. Unless the bore-hole is entirely through rock or other waterproof substance, the hole, as it is made, is lined with steel tubes, and thus, when the water-bearing stratum is reached, the boring tool quickly passes through it, to be followed immediately by the tube. The latter shuts all the water out, and so the hole is completed without trouble. The above method is often used for sinking wells for obtaining water, and since the hole is lined with tube such wells are called tube wells, but when they are made in connection with mining operations they are referred to as bore-holes.

A reader of the above will be inclined to ask what becomes of the earth, rock, etc., out of the hole. The carpenter's auger sends up a stream of chips or shavings, and it is evident there is something to be got rid of in a similar way when making a bore-hole. The explanation is that the hole is bored a few feet at a time, and then the rods with the boring tool at the end are drawn up, and another kind of tool is let down the hole. Thus the debris is scooped up if it be in small pieces, or drawn out if, as is sometimes the case, it is a solid core of hard rock.

We see, then, that what is sometimes a formidable

obstacle to the sinking of a large shaft is no obstacle at all to a small bore-hole, and that is the real secret of this interesting method of shaft-sinking.

A number of bore-holes are sunk forming a ring, slightly larger in diameter than the shaft that it is proposed to dig. These holes are carried down until the water-bearing stratum has been passed. Then a tube of small diameter is lowered down into each bore-hole, and through it is pumped a liquid known as brine. The brine passes down the small tube and out at the bottom,

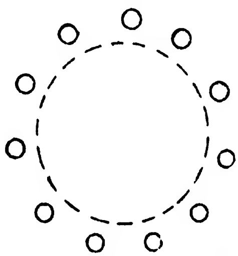
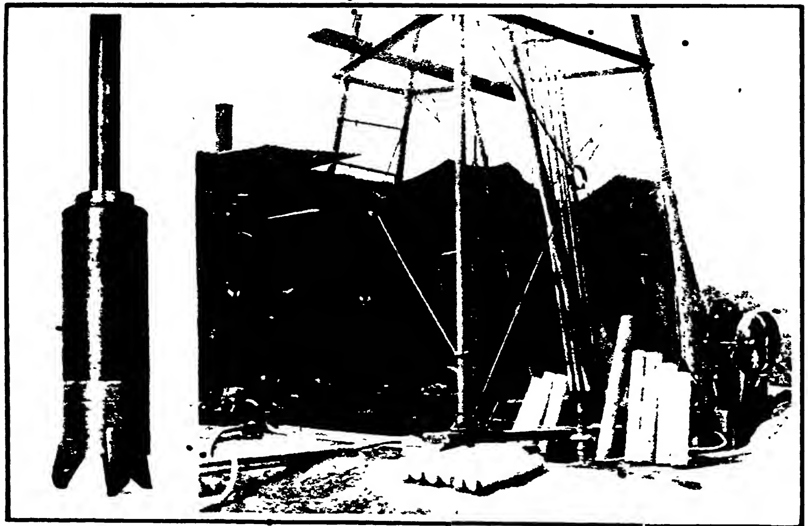


Fig. 18. Diagram showing the method of sinking shafts through wet strata by freezing. The dotted circle indicates the proposed shaft, the small circles the bore-holes by which the ground is frozen.

then flowing upwards through the bore-hole itself. Now brine consists of water in which certain chemicals have been mixed which render it non-freezable. By means of a refrigerator, the working of which is explained in another chapter, this liquid is made very cold, well below freezing point, and consequently, when it circulates through the bore-holes it gradually causes the surrounding earth to become frozen solid. The column of frozen earth around each bore-hole gradually gets larger and larger, until it meets and unites with the adjacent columns, and then there is a solid wall of frozen material all round



WELL BORING BY MACHINERY

This shows a machine which bores holes in the ground much as a carpenter bores holes with an auger

A WELL-BORING TOOL

This is one of the tools used in boring wells. It is turned round from above by means of the vertical rod, and the teeth at the bottom cut away the rock in a circle, leaving a solid core to be drawn up later

the space in which the shaft has to be dug. It is then possible to dig through the wettest stratum, just as if it were dry ground. The brine has to be kept circulating continuously day and night, until the lining of the shaft has been put in and the shaft itself made waterproof. Then the brine pumps may cease, the inner tubes can be drawn up, and the bore-holes abandoned.

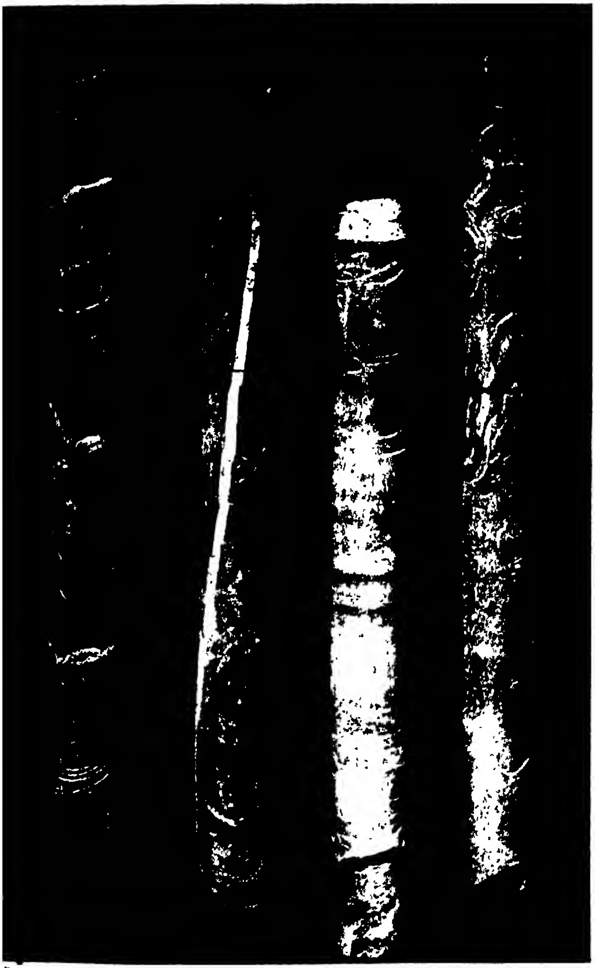
It is needless to say that the wonderful modern power, electricity, is making its way into the coal mines. For some things it is eminently suited for the purpose. It used to be the custom to drive underground machinery by steam from boilers on the surface, but that was a most wasteful proceeding, for during its long journey the steam became cooled and partially condensed, and therefore lost a great deal of its power. Nothing of this sort happens, however, with electricity flowing along a wire. If a certain quantity be pumped in at one end by a dynamo, that amount will come out at the other end. It is true that a certain amount of energy is consumed on the way, owing to the resistance which the wire offers to its passage, but that is very trifling compared with the immense loss which occurs when steam passes through a long pipe. Against the use of electricity, however, it is sometimes urged that its propensity for making sparks is a source of danger in the mine. In theory this can be entirely obviated, but in the rough and tumble of actual working in the remote parts of a coal mine it may not be possible always to avoid such dangers. Still, it is being largely used for working such things as pumps, for hauling the trains of corves along the main roads, and also for coal-cutting machines.

Electricity, however, has a rival for this kind of work

in compressed air. The air is compressed on the surface by means of a pump driven by a steam engine. It then passes through pipes down the shaft to wherever it is required. It can be used anywhere with perfect safety, since it has no power to cause sparks or set light to anything. On the other hand, it has a certain value apart from the work it does, inasmuch as it is liberated when it has performed its task, and so forms a supply of fresh air in parts of the mine, perhaps, where fresh air is none too plentiful.

The coal-cutting machines referred to just now are interesting inventions. To understand their working we must see for a moment how the collier gets the coal by hand. He first of all " holes " the coal, that is to say cuts with his pick a deep horizontal groove in the coal at the bottom of the seam, or in some cases in the clay which usually underlies the coal. As he does this he generally props the coal up with short pieces of wood known as sprags. When he has done this for a sufficient length he knocks the sprags away, and in some cases the mass of coal falls down of its own weight. In other cases, however, it has to be forced down by driving wedges at the back of the overhanging mass, or else blasted down with explosives. The fall of the block of coal may cause it to break up sufficiently to be loaded into corves and sent out of the mine, but if not it is broken up by hand.

The function of the coal-cutter is generally to do the "holing." There are several kinds of machines for this purpose. Most of them consist of a carriage which travels on rails along the face of the coal, on which the electric or pneumatic motor is fixed and from which projects the actual cutting appliance. In some this appliance



By permission of] [*Messrs. Duke & Ockenden, Ltd., Littlehampton*

STONE CORES

These are interesting examples of the Stone Cores cut out of the solid rock, by the Well boring Machine.

takes the form of a horizontal disc with detachable chisels or teeth fixed to its edge, so that it is in effect a circular saw. The machine turns this round, and at the same time travels along, thereby cutting what is practically a wide saw-cut, either at the bottom of the seam or in the underclay which is beneath it.

Another type of machine consists of a straight bar studded with teeth, which is worked rapidly to and fro, while another type has a spindle with teeth on it, set in a spiral like the thread of a screw. This revolves rapidly, and the teeth cut their way through the coal, while at the same time, being in a spiral arrangement, they tend to clear out of the cut the loose matter which they produce, the "sawdust" you might almost call it.

Yet another type has a chain something like a magnified bicycle chain with chisels attached to the links. This chain is endless, that is to say has its two ends connected together, and it is stretched over two wheels. One of these is at each end of a steel arm, or "jib," to give it its technical name. One end of the jib is attached to the machine, and the wheel at that end is turned by the motor. That causes the chain to travel round and round, so that the chisels are continually moving along one side of the jib, round the wheel at the other end, and back along the other side. Then, when the arm is brought against the coal, the travelling chisels cut it as a saw would do.

These, we see, are all much of the same nature and work in much the same way, namely as a saw, cutting their way through the coal or clay.

There is, however, another kind of machine altogether. These may be described as automatic chisels or picks,

worked by compressed air. There is an air cylinder generally mounted on wheels, while inside the cylinder is a piston with a piston rod projecting through the end. The chisel is attached to the end of the piston rod, and an automatic valve causes the air to be admitted, first at one end of the cylinder and then at the other, so that the piston rod is alternately forced outwards and drawn inwards. Thus the chisel is made to strike a rapid succession of blows upon the coal. Of all these machines, those which have a disc are the most used.

And now I find I have written quite enough to form one chapter, but as there are many more inventions of great interest connected with collieries well worth description, I shall deal with them in the next.

CHAPTER VII

MORE INVENTIONS IN THE COLLIERY

At some collieries as many as five hundred full trucks are raised from one shaft every hour. In order to deal with such a large number of trucks the cages are often made with three floors or decks, and consequently the unloading and loading of them is not quite a simple matter. It would be impossible to raise the cage until one floor was level with the surface, push off the full trucks, and push on some empty ones, then move it until the next floor was level with the surface, do the same thing, and then again for the third floor. That would mean far too great a waste of time, so several very ingenious arrangements have been made by which the three floors can be unloaded and reloaded at the same time. One of the most interesting of these is shown in illustration Fig. 19. At each side of the main cage (the one which goes up and down the pit) there is another cage which only moves a short distance. These two cages are, in their normal position, so placed that their floors are level with the three floors of the main cage when it is at the top of the pit.

It is always arranged that the trucks containing the coal shall leave the cage in one direction, while the empty ones shall come from the other direction. We will assume that in this case the movement is from right to left. As soon as the cage arrives at the top, the two trucks on its top

floor are pushed away to the left and two empty ones are pushed into their place. At the same time, the two full trucks on the second deck are pushed on to the second deck of the left-hand cage, while two empty ones from the right-hand cage are pushed into their places. The bottom deck is cleared and reloaded in the same way and at the same time. Thus all three decks are cleared as

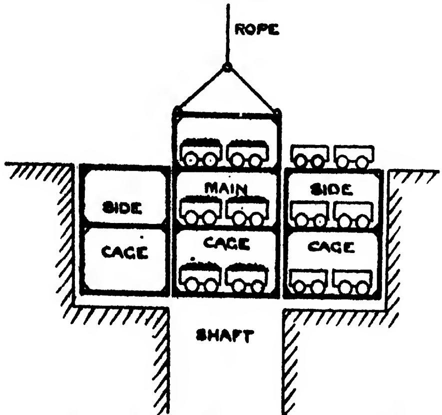
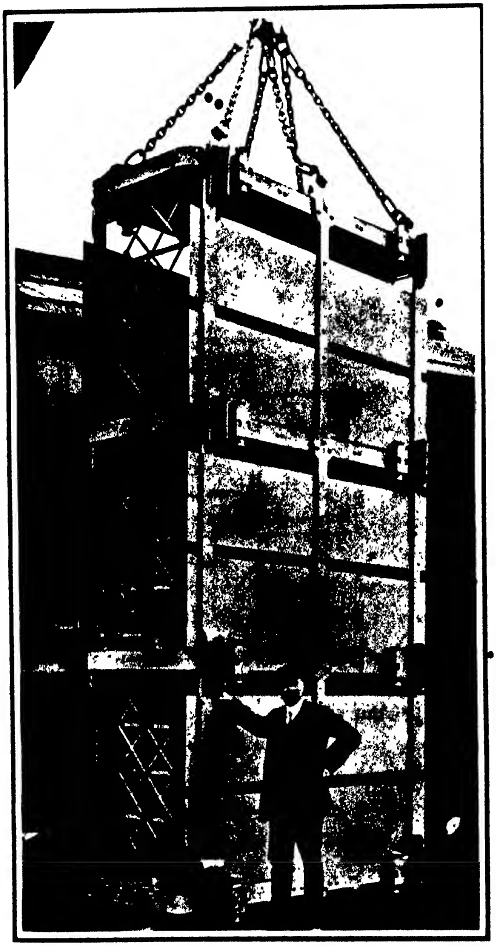


Fig. 19. An ingenious arrangement for unloading and re-loading the three decks of the cage at the same moment. (Suitable for the *top* of the pit.)

quickly as one could be, and the middle cage is then ready to pursue its downward journey once more.

While it is going down and up again, the side cages are raised by hydraulic power until their middle decks are level with the surface. Then two full trucks are pushed off the left-hand one and two "empties" on to the right-hand one. Next they are raised a stage further so that their bottom decks come level with the surface, after which they return to their normal position ready for the next time the main cage comes up.



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A THREE-DECK COLLIERY CAGE

This is the kind of conveyance in which a collier goes to his work and by which the result of his labours is brought to the surface. It has three floors, as described in the text, and it will be noticed that there is not room on any of them for a man to stand upright.

Our next illustration (Fig. 20) shows an arrangement for a similar purpose which is sometimes used at the bottom of the pit. There are four small cages hung by two wire ropes which pass over pulleys. The full trucks of coal from the workings, we will assume, arrive from the right at the level A, B, while the empty ones pass away to the left at the same level. When it is at the bottom of the shaft, the main cage stops with its top floor at this level, and so the empties can be pushed

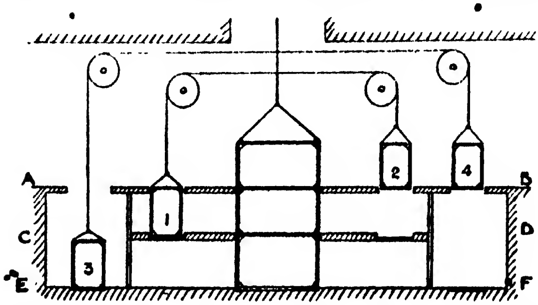

Fig. 20. Another arrangement similar to that shown in Fig. 19 but suitable for the bottom of the pit.

straight out off the top deck and the full ones pushed into their places. Those on the middle deck are dealt with in the same way, at the level C, D, and those on the bottom one at E, F. Then the cage is ready to return to the surface. While on its journey the trucks are handled as follows. The empties at C, D are pushed into the small cage 1, and at the same time some full trucks are pushed into No. 2, and the weight of the full trucks in No. 2 causes the cage to drop down to the level of C, D, at the same time pulling cage No. 1 (which only contains empties) to the top.

Cages 3 and 4 serve the bottom deck of the main cage in precisely the same way, and as cages 1 and 3 are made a little heavier than 2 and 4, no sooner are they unloaded than they run back to their normal positions (as shown in the diagram), ready for the next time the main cage comes down. This arrangement, you will observe, is quite automatic. No power is required to work it, except that of the men who push the trucks on and off the cages.

Our next illustration (Fig. 21) is a diagram showing an ingenious arrangement for handling the trucks on the

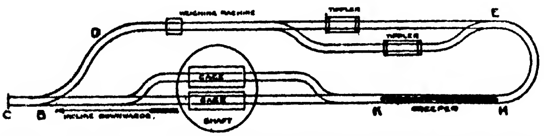

Fig. 21. An example of the ingenuity displayed in arranging the lines at the top of a coal pit so that the trucks of coal are handled quickly and with little labour.

surface as they come from the cages. Each pair of lines represents a pair of rails. Empty trucks, we will assume, are waiting on the lines to the right of the cages ready to be loaded into them. As soon as a cage arrives at the surface the full trucks are pushed off it to the left and empty trucks are pushed into their places. The full trucks then run down by their own weight until they reach B, that piece of line being made on an incline on purpose. Beyond B, however, the line quickly inclines upwards, so that each truck quickly stops near C and then runs backwards, going to the left at B and through D until it comes to the weighing machine. When the weight has been arrived at, it is pushed along to one of the tipplers, one truck going to one tippler and the next to

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A WONDERFUL AUTOMATIC CONTRIVANCE

This shows a pair of Tipplers as described in Chapter VII. The farther one has a full truck inside it; the nearer one has just emptied a truck which is receding in the distance.

The trigger like arrangement in the foreground lets the trucks run downhill to the tippler one at a time. Each full truck pushes out an empty one; the empty one sets the tippler turning, and the turning sets another full truck free. Thus the apparatus goes on working itself, without attention.

the other, and so on, alternately. In these the truck is turned over and its contents shot on to a screen; next it is pushed on towards E, and then it runs down until it reaches H. Here it encounters an arrangement called a creeper, and this hauls it up an incline to K, where it is level with the cages and ready to be pushed on to one of them and go down the mine once more.

Tippler, in engineers' language, is not a term of reproach; it means a construction for tipping trucks. It consists, first of all, of two strong iron rings large enough for a truck to pass through easily. These rings are placed vertically, at a distance apart a little greater than the length of a truck, and they are supported on rollers so that they are able to turn easily. Between the two rings, and connecting them, is a deck with rails for the trucks, while there is a framework also connecting the two rings, so arranged that it holds the truck firmly so that it cannot fall out even if turned upside down. The action of it is this: the truck is run on to the deck and then the whole thing is turned over on the rollers. This empties the truck, throwing out the coal, which falls into a suitable shoot placed to catch it. The whole thing, with the truck inside it, is arranged so that it will turn right over, a complete somersault, until it gets back to its normal position with the deck of the tippler level with the rails leading to it. The empty truck is then pushed out the other side.

A creeper is a simple contrivance placed between the rails. There is a trough in which moves an endless chain, and to this chain are fixed a number of hooks. The trucks are pushed on to the creeper, and the first hook which comes along catches it by one of its axles

and pulls it to the top of the incline. When it reaches the top of the incline the chain passes down under a wheel, and the hooks are so arranged that when that happens they slip off the axle and leave the truck free. This simple contrivance is quite automatic; there is no necessity for anyone to connect the trucks to the creeper at the bottom or disconnect them at the top. It is not one of those things which we often hear about, but it is an example of a simple contrivance which quietly does a lot of work in an effective way.

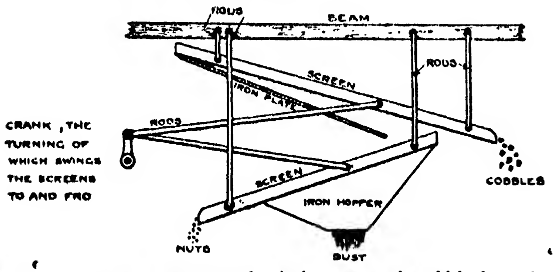

Fig. 22. A clever arrangement of swinging screens, by which the coal is sorted out into various sizes.

When the coal is emptied out of the trucks it falls on to a screen. In some cases this is simply a floor consisting of bars of iron placed parallel with spaces between. It slopes away from the tippler so that the fine coal falls through between the bars into a railway truck beneath, while the larger pieces slide on into another truck. The screens are often arranged, however, in a much more ingenious and effective way. Our illustration Fig. 22 is an example of this. At the top there is an arrangement of beams, and from them is suspended a screen formed of a trough of sheet iron with holes in the bottom. The coal falls on to the upper end of this

and rolls down, the smaller stuff falling through the holes and the largest pieces falling off the end. The coal that goes through the holes drops on to an iron plate, which leads it to the upper end of another screen placed beneath the first one. This has very fine holes through which only the dust passes, while the small pieces, or "nuts" as they are called, fall off at the end. The dust, when it passes the holes, falls into a hopper, or funnel as we might describe it, made of sheet iron. At some suitable place there is a crank, or something of that sort, connected by means of rods to the two screens, and this being turned round by any convenient power, keeps the screens continually shaking to and fro. Thus the coal is sorted up into three sizes and falls into three different receptacles. Moreover, the fact that these screens are continually shaking causes them to divide up the different sizes much more effectively than the simple screen of iron bars.

Sometimes the coal falls direct from these screens to the railway trucks in which it is to go away to its destination, but very often there is dirt mixed with it which has first to be got rid of in some way. In that case the coal is often made to fall from the screens on to what is known as a picking band. This consists of an iron trough, the bottom of which is continually moving in one direction. It is hard to see how such a thing can possibly be brought about, but it is really quite simple. The bottom is made up of plates hinged together so as to form an endless band, and at each end it passes over a hexagon roller, each side of which is the size of one of the plates. Thus it travels slowly but steadily along, carrying the coal with it, and a number of men and boys

stand along the side of it, picking out pieces of shale o other foreign matter as it passes. Sometimes a broa endless belt of cotton or rubber is employed instead o the band of iron plates.

It is not an uncommon thing to see coal advertised a "hand picked," and one naturally conjures up picture of people busily engaged sorting out huge heaps of coal Now it is needless to say that to sort out the coal fron a heap by hand would be a hopelessly expensive operation but sorting it out by means of one of these simple con trivances is quite another matter. It frequently happen that a seam may consist of several different qualitie of coal, and no mechanical contrivance can effectively separate them. If, however, it be put upon a picking band, each man will look out for one particular class o coal, and the moment a piece of that particular sort come past him, he will snatch it up and throw it into a truck near by. Other men are at the same time on the look out for the other qualities, and so the process of sorting by hand is made comparatively quick and easy. In some instances, these bands are as long as three hundred feet.

In some cases dirt is got out of the coal by washing it with water. It is a well-known fact, and one which is made use of in a number of different inventions, that if two things of different specific gravity be placed in water, the heavier one will sink to the bottom first. If the water be in motion, as, for instance, a running stream, it will then have the effect of separating the two pieces of material; for, suppose that the stream carries the heavier one a foot before it has had time to settle on the bottom, it will obviously carry the lighter body a further distance. Now, fortunately, the specific gravity of shale, which is

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SORTING ORE BY MEANS OF A PICKING BELT

The material falls upon the travelling belt, and the men and boys pick out the ore from the refuse as it is carried past them.

the commonest refuse in coal, is nearly twice the specific gravity of coal, and so this method can be used for separating the two.

The simplest form of coal-washer is merely a trough with little barriers, forming what might be described as submerged dams, across at intervals. The coal is fed on to the upper end of the trough, where it meets a stream of water running down. The water carries the light coal the whole way down the trough and delivers it over the end, but the shale has time to settle and so becomes caught by one or other of the barriers. It is usual to have two of these, which are used in succession, one of them being cleared of the accumulated shale while the other one is at work. The difficulty of having to stop the apparatus in order to clean it out has led to a very much improved form being invented. In this the trough itself moves upwards, very much in the manner of a picking band, as the water runs downwards. Thus the shale as it is caught is carried up and tipped off the top end.

Another variety of the same machine uses a stirring action instead of a stream. Of course, the principle of the thing is just the same, because a body of water going round and round in a circular vessel is practically the same as a stream. One is going straight while the other is going round a continual curve, that is the only difference, and so far as the power to sort out a light material from heavy is concerned, they are just the same. The machine consists of a cone-shaped drum of iron, placed with its point downwards, and, inside it, there is a vertical shaft or spindle with a number of arms or paddles attached to it. The vessel is filled with water and the shaft is rotated by machinery, so that the water is driven round

with an action very similar to the stirring of the liquid in a tea-cup. At the same time, more water is continually pumped in at the apex of the cone, which you will remember is at the bottom, and the coal with its impurities in it is fed in at the top. Thus, you see, there is the continual circulating of the water, and at the same time there is an upward movement due to the fresh water coming in. This upward movement is just sufficient to carry the coal upwards, and over the edge of the vessel, but is not sufficient to overcome the gravity of the shale, which consequently settles to the bottom. Here, at the apex of the cone, there are two doors one above another, with a space between them. The upper door is first opened, and the sediment at the bottom of the vessel falls through it to the lower door; then the upper door is closed and the lower door opened, and so the refuse is periodically removed without stopping the machine.

At some collieries there is a large plant for converting the coal into coke. Some use this merely as a means of getting rid of the slack and fine stuff which is otherwise unsaleable, for fine coal is as good as any other for this purpose. In fact, those collieries which make all their coal into coke have first to grind it all small. This coke, it must be understood, is somewhat different from the fuel which we can buy from the gasworks, and is used mainly in iron foundries and steel works. The old way to make this is in what are called "bee-hive" ovens; they are chambers of brickwork the shape of a bee-hive, and they are filled with coal through a hole at the top. There is a small hole at the bottom, through which a little air can get in, and after a time the heat which was left in the bricks after the previous charge had been taken out,

causes the coal to catch fire. If there were a plentiful supply of air, this would mean that the whole contents of the oven would be consumed, but since there is only a small and carefully regulated supply of air at the bottom, there is only just sufficient combustion taking place to heat up the whole mass and turn it into coke. When the requisite time has elapsed the fire is damped out, a door is opened at the bottom of the oven, and the coke raked out.

This is a very old idea, as is shown by a very interesting fact which I chanced to notice a short time ago. A few minutes to spare and a little idle curiosity led me to examine the files at the Patent Office in London, to see what were the subjects of the earliest patents granted in England. Among the earliest were patents granted to the then Lord Dudley (a name still known throughout the world in connection with iron and steel) and others, giving a monopoly in the manufacture of iron, using coal which had been "charked." This unquestionably meant coal which had been treated in the same way that wood was treated to make charcoal, and the process I have just described is exactly similar to the method of making charcoal. The patent I referred to is dated as far back as 1620, so the manufacture of coke is evidently no new idea, when carried on in the primitive manner which I have described. That brings us to the modern methods which have been invented for the same purpose.

There are several types of plant in use, but it will suffice if I describe one of them, as it will indicate the lines upon which they are all made. In the first place, we must notice, there is a lot of valuable gas given off in the process of coking which it is a pity to lose; and,

in the second place, the charging and discharging of the bee-hive oven is a slow and laborious process. It has to be done by hand, since the shape of the bee-hive oven does not lend itself to charging and discharging by any other means.

Now a modern battery of coke ovens consists of a long, rectangular building with a flat top, built largely, if not entirely, of fire-bricks. It is pierced through and through from side to side by tunnels, about 2 feet wide and as long as the battery is wide, namely about 30 feet. Each of these tunnels constitutes an oven.

Formed in the brickwork around and under the ovens there are flues for heating them, and the heat is obtained from the gas which the ovens themselves produce.

Sometimes they are filled through holes in the roof, but the more up-to-date way is by means of a machine called a compressor. This travels up and down on rails in front of the ovens. It has upon it a large box or bunker which is filled with small coal. This can be caused to slide down a shoot into a kind of mould called the cake chamber. The coal is made a little wet, so that it will bind together, and the machine compresses it into a huge cake, weighing perhaps 10 tons. The floor of the cake chamber is separate from the rest, and the machine is able to slide it forward into the oven, carrying the cake with it. The cake is in size and shape a nice easy fit in the oven, and when it has been deposited in its place, the cake plate is withdrawn. The ends of the oven are then closed with doors which are luted with clay to make them airtight. The heat of the burning gas in the flues soon causes the coal to begin to give off gas, which finds a means of escape through a vertical pipe passing through

the roof of the oven. Then it goes into a large pipe, running the whole length of the battery, which takes it away to a by-product recovery plant. Here it is treated for the recovery of various chemicals which it contains, after which it passes back to the ovens in the flues of which it is burnt.

Even then, however, the gas is not done with. The tar, ammonia, etc., have been extracted from it, and it has been burnt to generate heat, but it can do more work even yet. For it is still very hot. Therefore the waste gases from the flues around the ovens are not led direct to the chimney, as we might expect, but to steam boilers, where they provide sufficient heat to generate steam for working the colliery, and after that they pass to the chimney.

In some cases there is a surplus of gas, after all that is required for heating the ovens has been taken, and in that case it can be used either for burning under boilers and so generating steam, or else for driving gas engines. The latter is the more modern practice.

It may seem a descent to turn from the vast coke-making plant to a small hook on the colliery cage, but what is known as the " detachable hook " is not only a very clever invention, but a very valuable safeguard. When the powerful steam engine whirls a cage up from the depths of the pit, the engine-driver has to stop the cage in the correct position. For this purpose he has a powerful brake, which he can apply to the drum on which the rope is wound. Still, he may make a mistake and not apply the brake in time, or his brake may fail, and the result will be to overwind the cage, as it is termed, that is to say, pull it right up into the pithead frame, and it

maybe, throw out the men in it to the bottom of the shaft. It is the purpose of this hook to prevent such an occurrence. It consists of three little plates of steel, of a curious shape, fixed together in the middle by means of a single pin, so that they open and close something like a pair of scissors. The rope is attached to the top of this clip, and the cage to the bottom. The rope passes upwards through a hole in a plate fixed in the pithead frame, and if this clip should be pulled into the hole, it has the effect of closing the " scissors," as it were. That liberates the rope from the cage, and at the same time grips the plate itself. When the cage stops in its proper place the clip is left just below the plate, but if an " overwind " takes place, the only result is that the rope is detached and the cage is left safely hanging by means of the clip. It is so arranged that the rope cannot possibly be detached by any other means except the drawing of this clip through the hole in the plate designed for the purpose.

CHAPTER VIII

THE MAKING OF A "LANCASHIRE" BOILER

THE way in which heat is used to drive a steam engine is to make it expand water into steam in a closed vessel. The expansion causes pressure, which is then used to push against a piston in a cylinder. Nearly everything expands with heat, but water, when it changes into steam, expands about 1600 times, and it is that great volume of expansion which makes it so convenient for the purpose.

Before proceeding to examine the modern steam boiler, it will be well to remind ourselves of a few fundamental facts about steam.

You cannot make water hotter than the boiling point. If you make a cup out of paper and fill it with water, you can put it on the hottest part of a fire without its being burnt. The water will boil, and in time will boil away, but so long as it is in contact with water the paper will not burn. That is because the heat which passes from the fire to the paper is quickly handed on to the water, and any heat which reaches the water after it has attained boiling point does not make it any hotter, but is employed in turning it into steam. So the water cannot rise above boiling point, which is not hot enough to consume paper, and so the paper remains unconsumed.

At some hotels on high mountains it is impossible to make tea. That is due to the same cause. The pressure is lower there than at the sea-level, and so the water boils

at a lower temperature than usual, too low to make tea with. These two facts illustrate the relation between the pressure of steam and its temperature. The boiling point to which we are accustomed, namely 212 degrees Fahrenheit, is the point at which water boils when it is subject to a pressure of 14·7 lbs. per square inch, the normal pressure of the atmosphere. And just as the boiling point falls when the pressure is reduced, so it rises when the pressure is increased. Suppose that a boiler were half filled with water, and the other half with air at a pressure of 20 lbs., then the water would not boil until it was heated to 228 degrees instead of 212; if the pressure were 100 lbs. it would have to be 327 degrees, while at 160 lbs. the temperature of boiling point would be 363 degrees. The temperature of boiling point varies, therefore, with the pressure.

Another important thing about steam is its latent heat. If we take a pound of water at, say, the temperature of melting ice (32 degrees Fahrenheit), and apply about 180 units of heat to it, we shall, if it is open to the atmosphere, raise it to the boiling point. After that we can add another 966 units without making anything a single degree hotter. All that the 966 degrees will do is to turn a pound of water at 212 degrees into a pound of steam at 212 degrees. That amount of heat (enough to melt 3 lbs. of steel) will, therefore, as far as the senses or the thermometer can tell, entirely vanish. As a matter of fact, we can recover it, so we know that it has only become latent.

This latent heat is useful, in a way, because, when the steam in the cylinder loses heat because of the work it has done in pushing the piston, it begins to condense. A little of it does condense, and then the latent heat

in that small quantity is liberated. It appears once more as "sensible" heat (that is, heat which can be detected by the thermometer), and is added to the steam which remains, thereby preventing it from condensing so readily as it otherwise would do. Still, the bulk of the latent heat remains latent in the steam until it reaches the open air or the condenser, as the case may be. In the former case it passes into the air when the steam condenses. In the latter it passes into the cold water, which is used to condense the steam in the condenser. In either case the greater part of it is entirely wasted.

Now when water is evaporated at a pressure of 100 lbs., only about 876 units become latent, instead of 966. At 200 lbs. it is only 840, and so it goes on decreasing as the pressure gets higher.

Thus the higher the pressure, the less valuable heat do we lose, owing to its becoming latent, a reason why high steam pressures are desirable.

Moreover, a steam engine, as everyone knows, works by the steam pushing one or more pistons, first one way and then the other. The steam enters the cylinder at a certain pressure per square inch, and it is able to exert that amount of force upon every square inch of surface which the piston presents to it. Therefore, to make a more powerful engine, we need to increase one of two things, either the pressure of the steam or the surface of the piston. The increase of the piston area involves large cylinders, and a large engine generally; therefore it is, speaking generally, best to make the engine as small as it can be for the work it has to do, and make the pressure of the steam as high as possible.

It is easy to see, indeed, that an engine worked by

steam at, say, 50 lbs. pressure would need to be larger than one worked by steam at 100 lbs., if it is to do the same work. Therefore, we have here another reason why high steam-pressures are much used in modern plants.

In the old atmospheric engines, and in the early engines of Watt, the boiler was little more than a kettle. There was a safety valve, which allowed the steam to escape when it reached the pressure of 1 lb. per square inch. The steam was, in fact, only indirectly the motive force, for it did not push the piston, it only expelled the air, so that when condensed it would leave a vacuum, and it was the pressure of the air acting against the vacuum which moved the piston.

It gradually became apparent, however, that there was advantage to be gained by using the force of the steam, as well as the air pressure, and so there grew up a demand for strong boilers which would be able to resist heavy pressures. From that time until now the manufacture of boilers has been steadily improved, until 200 lbs., and even 250 lbs., per square inch is not infrequently the normal pressure at which steam is raised.

And here a little explanation is desirable as to the word pressure. In the earlier and more theoretical part of this chapter we used it, as it is generally employed in theoretical considerations, to mean the pressure above a perfect vacuum. For instance, when I said that water under a pressure of 20 lbs. per square inch boiled at 228 degrees, I meant 20 lbs. including the 14·7 lbs. of the atmosphere. That is the "absolute pressure." In practical engineering, however, the word pressure generally means "gauge pressure," or the pressure shown by the gauge on the boiler, and that excludes the atmo-

spheric pressure. The 20 lbs. absolute pressure referred to just now is the same thing as 5·3 gauge pressure. Now that we have left theory behind, so far as this chapter is concerned, and have come to things practical, we will follow the usual practice and use the gauge pressure for the remainder of the chapter.

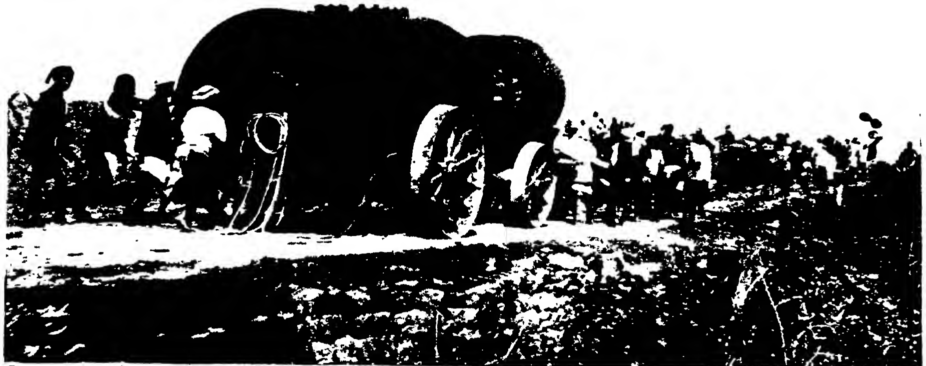
The feature of a modern boiler, then, is enormous strength to resist the high pressure. When George Stephenson first conceived his idea of a successful steam locomotive, he told a friend that it would have to be "fitted together as carefully as a watch." The watch was then the acme of delicate and painstaking workmanship. Nowadays a huge "Lancashire" boiler, 30 feet long and 9 feet in diameter, and weighing about 40 tons, is constructed with as much care and attention to detail as any piece of mechanism, be it a watch or anything else.

Large boilers for use on land are generally "Lancashire" boilers, or water-tube boilers.

A "Lancashire" boiler is one of those large cylindrical ones with two furnaces in it, which are to be seen at many factories, and also at large buildings for generating the steam for heating. Most people have seen them at some time or other. As a rule, they are almost hidden in the brickwork which supports them, little more than one circular end being visible. In that end are two circular openings, the upper half of each being closed by a door. Each of these openings is the end of a cylindrical steel pipe, which forms a flue running right from back to front, the whole length of the boiler. The furnaces are formed in the front ends of these flues, and the hot gases from the fires pass through them to the back of the boiler. There they do not go direct to the chimney, as many

people suppose, but enter a chamber in the brickwork, known as the "downtake," which leads them down into a flue formed in the brickwork underneath the boiler, along which they return to the front. On arriving at the front, the underneath flue divides into two, one of which returns from front to back along each side. Thence the gases go to the chimney.

And here a word of explanation is necessary about the word gas. We are so in the habit, in the ordinary affairs of life, of speaking of "the gas," thereby meaning something which will burn, that when one speaks of the hot gases which leave a boiler fire and pass along the flues, a reader is very apt to think of gas of an inflammable nature, and wonder what in the world such gas is doing in the flues of a boiler. The explanation is that "the gas" is only one gas of many, or rather it is a mixture of a few gases out of many, all equally entitled to the name of gas. When a fire burns in a boiler furnace great quantities of the gas oxygen need to be drawn in to keep the fire going, and since the most abundant supply of this gas, the air, contains also about four times as much nitrogen mixed with it, the latter has to go through the fire as well. In the fire itself the oxygen combines with the carbon of the coal and emerges from the fire as carbonic acid. Thus there is a continual stream of gases, mainly nitrogen and carbonic acid, in a *very hot state*, coming away from the fire; and to get good value, in the shape of heat in the boiler, in exchange for the coal burnt, it is necessary to carry those gases along for some considerable distance in contact with the metal of the boiler on the other side of which is the water to be warmed. That is in order to give the heat in the gases the best



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NATIVES AND ELEPHANTS HAULING A LARGE BOILER

possible opportunity of "soaking" through, as it were, into the water; and it accounts for the use of the long brick flues, in addition to the two cylindrical ones.

And now we can turn to the methods by which these huge steel cylinders are made. The shell of a good "Lancashire" boiler, although it may be as large as 30 feet by 9 feet, is often only made of four plates. They have to be about 8 feet wide and 30 feet long. First of all they are planed in a planing machine to make

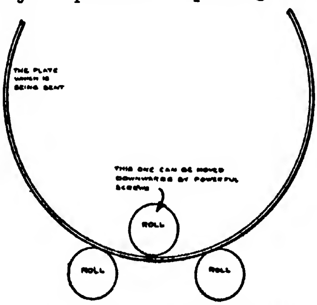


Fig. 23. This shows how three rolls bend the boiler plates to a circular form.

their edges perfectly straight, smooth, and square. The machine is like a large table, on to which the plate can be fastened by powerful screws, and while it is so held a small carriage, as we might call it, travels along, carrying a cutting tool which takes a shaving off the edge, very much as a carpenter planes the edge of a board. Another carriage, at the same time, does the same to one end, and then the plate is turned over, and the other side and end treated in the same way.

Then the plate is taken to the bending rolls. This machine consists of three rollers, two of which are fixed, while the third can be moved slightly by powerful

screws. The arrangement of these rollers can be seen from Fig. 23. To start with, the plate is quite flat, but as it passes backwards and forwards through the rolls, the middle roll is screwed gradually downwards, and so the plate is gradually bent into a perfect circular curve. It finishes up as a drum with two rollers on the outside of it, and one, the movable one, inside. Then the movable one is detachable, so as to get the drum out of the machine. The two ends of the plate are then joined together by means of a narrow plate of steel (called a cover plate, because it covers the joint), which is

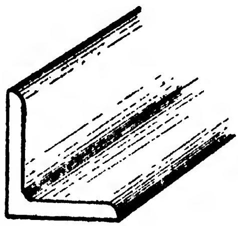


Fig. 24. This shows what is meant by "angle-iron."

riveted on. Two of the drums are made slightly smaller in diameter than the other two, so that they just fit inside them, and so the four plates are connected together telescope fashion, being firmly fixed to each other by rivets.

The back end of the boiler is made of a single plate of steel, which is heated until it is soft, and then turned over all round its edge until it forms a huge, shallow circular dish, just large enough to fit into the end of the shell, where it is secured by rivets.

The front end is different. It is not turned over on the edge, but, instead, a ring formed of "angle iron," or rather steel, is fitted to the shell, and the front is riveted to it.

"Angle iron" (or steel) is so called because of the shape of a section across it. If such a bar be sawn across, its shape will appear like that shown in Fig. 24. To make the angle ring just referred to, a bar is bent by rolls, just as the plates were, into a ring, and then its two ends are welded together.

The flues which run from front to back are a very important part of the boiler, and are made with great care. The outer shell can, as far as its shape is concerned, take care of itself. That is because the pressure is inside it, acting outwards, and when that is the case, the form which a vessel tends to take under the influence of the pressure, is round. Indeed, were the boiler to be made any other shape, oval, for example, the effect of the pressure would tend to make it round. Therefore, since it is round to start with, it has no tendency to alter under the pressure. With the flues the opposite is the case. There the pressure is outside and is acting inwards. Under those conditions, the tendency is for the flue to be crushed flat. All the time the boiler is at work, therefore, the steam is tending to crush in the flues, and it would actually do so, unless they were made of such a form as to be able to resist it. Moreover, there is the expansion due to heat to be taken into consideration. The boiler is made cold, but when it is set to work it is very hot, and the greatest heat is on the flues. The shell of the boiler is heated as well, but not to the same extent as the flues; and, therefore, they tend to expand more than the rest of the boiler does, and unless some provision were made for it, they would push out the ends to which they are attached.

Now let us, in imagination, watch the manufacture

of a boiler flue, and we shall be able to see how these two forces are resisted. A plate is first bent in rolls, in just the same way as the large plates which we were discussing just now. Instead of its joint being covered with a cover plate, however, it is heated in a furnace until it is soft, and then it goes to the steam hammer. Here we see it placed upon a kind of overhanging anvil, so shaped that it reaches into the interior of the drum and supports it inside, while the hammer pounds upon the outside and welds the two edges together. In that way we make

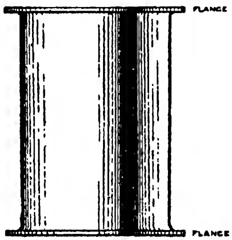


Fig. 25. A section of a boiler flue. It is made of a plate, bent round and the two ends welded so that it forms a tube. Then the flanges are bent over.

a solid, jointless steel drum, about 2 feet in diameter and several feet long. Then it goes to another furnace, where it is heated along one edge only, and from there it is taken to the flanging machine. In this it is clipped down by its cold end on to a revolving table and slowly turned round. At the same time, a roller comes over and presses the hot edge outwards. Another roller supports it underneath, and the mutual action of these rollers and the revolving of the table quickly turns the edge over all round, until it is at right angles to the body of the drum itself. This turned-over part is, in engineering parlance, a flange, and so the process is known as flanging.

When this has been done to one end the other is heated and treated in the same way, so that the final result is as shown in the sketch Fig. 25.

Next there are holes drilled in the flanges, so that a number of these short "pipes" can be riveted together into a single pipe, 30 feet or so in length, suitable for the flue of a boiler; and one does not need to be an engineer to see how those flanges stiffen the flue, and enable it to

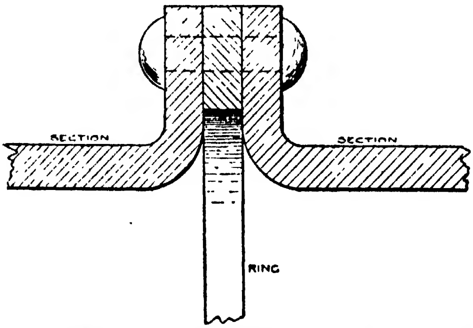


Fig. 26. Here we see how the sections are combined together to form a flue.

resist those forces which, if they could have their way, would crush it up flat.

And before they are riveted together there is something else which we must notice. A number of flat steel rings are made with holes in them, spaced exactly like those in the flanges, and between every pair of flanges one of these rings is placed. Fig. 26 will show just what I mean, and will also enable us to see what flexibility these joints give to the flue, enabling it to suffer compression when it tends to expand by the heat. We may take Fig. 26 as showing a joint when it is put together, and the next one, 27, as showing (in an exaggerated

form) how it would be when heated. Under these conditions, instead of pushing outwards the ends of the boiler, each flange springs a little and the length of the flue remains the same.

The furnace is formed by means of a sort of floor of firebars, as they are called. They are made of cast iron, and are laid parallel, with small openings between them through which the air can pass. Inside each flue, about 6 or 7 feet from the end, there is a bridge, as it is called, of firebrick, on which the further ends of the firebars

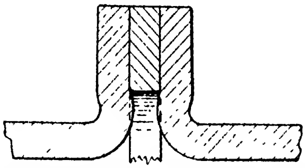


Fig. 27. This shows (in an exaggerated form) how the joints "give" so as to neutralize the effects of expansion by heat.

rest. Thus air which enters in at the lower part of the entrance to the flue, has to pass through the grate between the firebars and so into the fire. The bridge prevents it getting into the flue, except through the fire. There is considerable skill required in forming the fires under a boiler. The fuel has to be spread in a thin, even layer over the firebars, so that enough air will get to every particle of it to ensure quick and thorough combustion, and, at the same time, not a particle of air must, if it can be avoided, pass into the flues, except through the fire. If by some carelessness any small part of the grate be left not covered by fuel, air will get in there, and will quickly lower the temperature of the flues, and thereby impair the working of the boiler.

In the further end of the flues, beyond the end of the

furnace, there are often cross-tubes, strong pipes of steel riveted or welded to the flues. These have several advantages. For one thing, they strengthen the flues and help them to resist that crushing force of the steam which I referred to just now. Then they add to the heating surface, for they are full of water and are in communication with the interior of the boiler, and so the heat can get through them to the water. They also form an obstruction in the path of the hot gases, causing the current to be broken up, and making every hot particle come into contact with the heating surface and give up some of its heat.

Some boilers are fitted with corrugated flues. These are very like those which I described just now, only they are rolled between rollers, which have flutes or corrugations in them. These corrugated flues might be likened to a sheet of ordinary corrugated iron, such as is used for temporary buildings, bent round like a tube (with the direction of the corrugations running round and not lengthwise, mind), only, of course, the corrugations are larger and the metal thicker. The corrugations fulfil three functions, just as the cross-tubes do. They stiffen the tubes and help them to resist collapse; they increase the heating surface; and they enable the flue, when it tends to expand, to spring inwards, after the manner of a concertina.

Marine boilers cannot, obviously, have the brickwork round them which a "Lancashire" boiler has. They are, therefore, made shorter, and the flues are placed nearer the bottom. The gases from the flues pass at the back into a chamber called the combustion chamber, which is formed of steel and is inside the boiler itself,

and thence they return to the front through a lot of small tubes. Emerging from these tubes, at the front of the boiler, they are led upwards by a kind of hood, made of sheet iron, to the chimney, so that the chimney is just about over the heads of the firemen, instead of being at the other end, as is the case with the land boiler.

Every part of a boiler is made with the greatest possible care. All the holes are drilled in exactly the right position, and the rivets are put in, as far as possible, by a hydraulic machine, which squeezes them with a force of many tons, thereby making the soft, hot rivet entirely fill its hole, also squeezing the plates, which it is connecting together, tightly, and so making a very sound joint. Then the joints are caulked, to make them perfectly watertight. This means that a tool, something like a rather blunt chisel, is hammered against the edge of each plate, so as to make it swell out slightly and press upon the adjoining plate. This is so effective that a well-made boiler, when filled with water at, say, 300 lbs. pressure per square inch (always half as much again as the pressure which the boiler is intended to work at), will be "drop-dry." That is to say, there will not be visible a single drop of water which has found its way through any of the joints.

The principal fittings on a boiler are the safety valve, which lets the steam escape as soon as it reaches a certain pressure, and so provides against the possibility of an explosion; a low-water alarm of some sort, to give warning, or in some way prevent damage through the water getting too low; the gauge, for showing the pressure, and the gauge glass, by which the attendant can see where the water level stands. These will, however, be referred to in another chapter.

CHAPTER IX

THE WATER-TUBE BOILER

WHAT has been said does not, of course, exhaust the various kinds of cylindrical boiler. There is the "Cornish" type, similar to the "Lancashire" but smaller, and with only one flue. There is the tubular boiler, in which the fire is underneath and the gases travel to the back through a brick flue, returning to the front through tubes which pass right through the water. The "Lancashire" is, however, the chief type for large installations on land, and the "Scotch" marine boiler for use on board ship. They may be said to represent the latest inventions for the purpose of raising steam in large quantities on lines which adhere to the old "kettle" idea. They are, in fact, lineal descendants of the kitchen kettle.

The water-tube boilers represent a development along a new line. There have been many different varieties of the cylindrical boiler, as I have just said, but there have been a still greater number of water-tube boilers invented. Perhaps this was only to be expected, for so long as the cylindrical form was adhered to there was not much scope for variety; but the tubular form started with no traditions to hamper its development, and, moreover, an arrangement of tubes might clearly take many different shapes. Many of these have passed into oblivion, however, so that at the present time there are not more than

three or four different forms in use for land purposes, and of them one is pre-eminent. This is known as the "Babcock" boiler, having been invented by an American engineer, Mr. G. H. Babcock, and now made by the firm which he founded.

The first of the kind was patented by him in 1867, but since then it has undergone such change that it is difficult to say when the present "Babcock" boiler was invented.

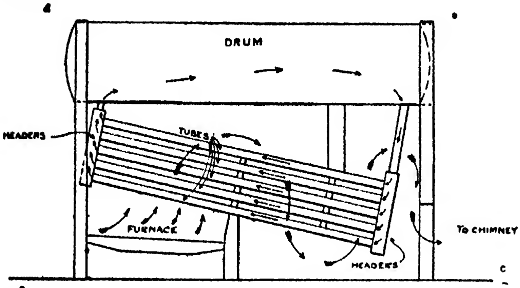
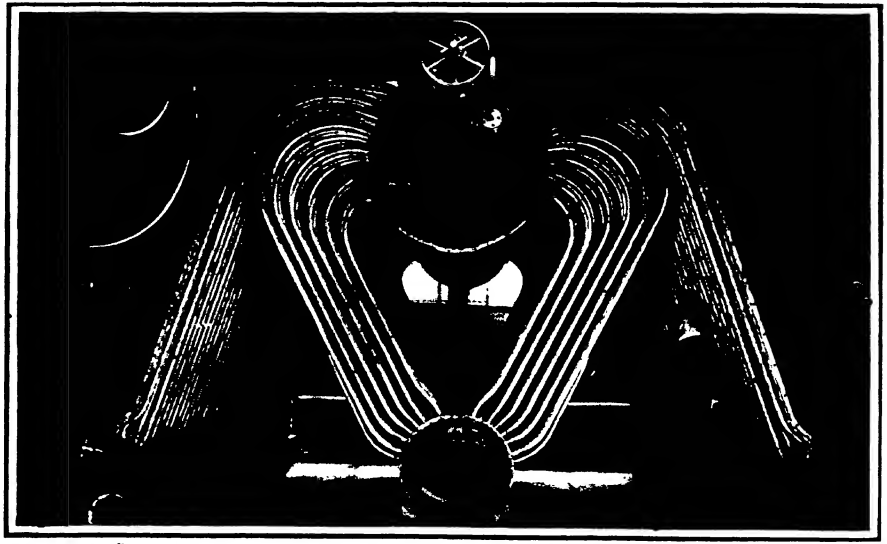


Fig. 28. Section showing how a "Babcock" water-tube boiler is constructed. The feathered arrows show the course of the hot gases. The plain arrows show the course of the water.

The features claimed for this boiler are its safety from explosion, and the facility with which it can get up steam. Its general form will be seen from the diagram Fig. 28. There is a small cylinder at the top, which is, in proper condition, half full of water and half full of steam. From the back end of this there depend a number of steel tubes, which terminate in wrought steel boxes called "headers." From the headers there spring other tubes at right angles to the first, pointing in the direction of the front of the boiler and sloping upwards as they go. At the front these tubes fit into other headers, which are connected by short



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INSIDE A MARINE WATER-TUBE BOILER

This is a view of the inside of a famous type of boiler. In use it is enclosed in an iron case and fires are made under it. The heat passes among the tubes, and some becoming hotter than others there is caused a circulation of water up the hottest ones and down the cooler ones. Thus the water is quickly heated.

tubes to the cylinder at its front end. The whole concern is built into a chamber generally of brickwork, and the fire is made under the higher end of the tubes.

The exit for the hot gases is at the back, and there are vertical partitions built up among the tubes which force them to pass in their journey from front to back in a zigzag direction up and down among the tubes. This has the effect of mixing them up well, and forcing them to give up their heat to the tubes as they pass.

To understand the advantages claimed for these boilers we need to consider for a moment what happens when we boil water. Everyone has seen the boiling of a saucepan or similar vessel of water, but few take the trouble to watch and see just what happens. Yet it is a most interesting subject, and well worth a little study.

When a vessel of water is put on the fire it is heated all over the bottom, and also to a less extent at the sides. Now water, you must understand, is a very bad conductor of heat, almost a non-conductor, in fact. If you were to try to heat a vessel of water by applying heat at the top of it you would find it almost impossible. You perceive the result of this when you go for a bathe. The water which feels so cold when you enter soon feels as if it were a warm coat around you, and you actually have the feeling that the water is keeping you warm. That is because it is such a bad conductor. The particles actually in contact with your skin become warm after a little while, but the neighbouring particles are so loth to accept the heat from them that they are not able to pass it on, and so, if you were to keep still in the water, you would soon become covered with a thin film of warm water almost as warm as yourself. The same thing

happens at the skin of a saucepan or boiler, only in that case the heat is considerably greater than that of the human body, and so the particles in contact are heated much more, causing them to expand to such an extent that they become buoyant and float up to the surface. Thus there is a tendency for the water from the bottom to rise, and owing to the extra heat which that water gets which is in contact with the sides over that which is at the centre, the water at the sides rises quickest, that at the centre at the bottom is drawn towards the sides to take its place, and the coldest water of all, that in the centre above the bottom, falls down to take the place of the last-mentioned. Thus a circulation is set up, upwards at the sides and downwards in the middle. It is that circulation, and that alone, which enables the water to be heated to any extent.

The same thing must perforce occur in a boiler, only being enclosed we cannot see it taking place.

If we let it get too hot the water in a kettle will, we all know, boil over. That is due to the heat at the bottom forming steam bubbles, which rise to the surface, meeting the downward current of cooler water and resulting in violent commotion. This causes the water to foam at the surface and run over the sides of the vessel. If, however, suitable partitions are placed in the vessel to ensure that the circulation shall be kept regular there will be no boiling over, however much the fire may be increased.

Now in a water-tube boiler there is a very strictly prescribed path which the water must follow. It goes up the inclined tubes, then up the front headers into the drum. After passing through the drum from front to back it descends the tubes at the back into the headers

there and into the lower ends of the inclined tubes, so completing the circuit, through which it goes over and over again. It is bound to perform this journey very quickly, and so the temperatures of the various parts of the boiler are kept, as nearly as it is possible to have them, at a uniform temperature, meaning uniform expansion of them all, and therefore the least possible straining of the structure owing to the expansion and contraction.

In the case of a boiler like the "Lancashire," where the water is free to do what it likes under the influence of the heat, there is no knowing exactly what happens. No doubt there are certain definite lines which the water takes, but these probably vary a great deal owing to variations in the heat in the different flues, and probably there is some time after the fires are started before the circulation gets going at all briskly. That would result in large bodies of comparatively cold water remaining still for considerable periods, and therefore powerful racking effects produced by the unequal expansion and contraction.

The second great advantage claimed for the water-tube boiler is that small, thin tubes are used instead of the large shell of the cylindrical boiler. If the latter should burst the whole district will know of it, and, indeed, may suffer in the ensuing hail of shattered fragments. A tube of a water-tube boiler may burst, however, with insignificant consequences.

It must not be inferred from this that cylindrical boilers are prone to explode, for such a thing is very rare. In order to guard against it, however, the greatest care in construction is necessary, and the makers of the water-tube boilers contend that they could make boilers easily

to stand much heavier pressures than the makers of cylindrical ones would dare to attempt.

Finally, the tubes can be thin. The shell and the flues of a "Lancashire" boiler have to withstand the total force of the steam exerted over large surfaces, while the small tubes have only very small surfaces, and can therefore be made much thinner. Therefore, when the boiler is started the heat can penetrate to the water so much the more quickly, and steam can be raised in a shorter time. In an electric-light station, for example, this is a very valuable quality, for there, if the day be bright, the machinery will be nearly all idle; but a sudden darkening of the sky may need the whole plant being got to work with but a few minutes' delay.

The same advantage is valuable on a warship, which may be ordered to undertake an unexpected voyage at any moment.

Of marine water-tube boilers there is a greater variety. One type will have to suffice for example. It is the "Thornycroft," which is largely used in the British Navy.

There are four drums, one at the top and three in a row at the bottom. All the bottom ones are connected to the top one by tiers of thin tubes and also by certain thick pipes as well.

The whole thing is fixed inside an iron casing, and two fires are made in the spaces between the three lower drums. The heat causes the water to circulate up the thin pipes and down the thick ones, the latter being slightly cooler because of their being farther from the furnaces. The reason why most of the pipes are curved is to allow them to expand and contract with the variations in heat.

The methods of construction are much the same whether the boiler be of the cylindrical or water-tube type. The drums are made of steel plates, with the joints either riveted or welded.

The tubes are fixed in their places by a method known as "expanding." The holes are drilled so that the tubes fit in them tightly, and then a tool called an "expander" is pushed into the tube and turned round. This tool is an arrangement of steel rollers which can be forced outwards. It is inserted and turned round, the rollers being gradually forced outwards from time to time. This has the effect of swelling out the end of the tube slightly, and making a perfectly tight fit in the hole.

There are a number of useful and interesting inventions which are used in connection with steam boilers, but they will be referred to in a later chapter.

CHAPTER X

SOME INTERESTING INVENTIONS ON THE RAILWAY

It would be quite easy to write a whole book on the subject of this chapter.[1] The inventions used on railways are simply innumerable; but here I will endeavour to give a few illustrations of the direction in which the inventive faculty has run in dealing with those matters which concern mainly the safety of the travelling public.

One's thoughts turn naturally, first of all, to the signalling, for the least observant passenger realizes that his safety depends very largely upon that. And one of the greatest inventions in connection with railway signalling is the interlocking apparatus. On showing to a friend recently a photograph of the interior of a large signal cabin, I was at once met with the remark, "Suppose the man should pull the wrong lever?" It seems to the uninitiated to be a fatally easy thing to do; but, as a matter of fact, it is not, for if he tried them he would find many of them immovable. Whenever a lever is pulled to lower a signal or to move a set of points, it locks in a safe position all the other levers, which might give a conflicting signal or cause an accident. For example, where one line crosses another the lowering of a signal permitting a train to pass along one line would *lock at danger* the signals which, if lowered, would permit a train to pass

[1] A general view of the working of railways will be found in "Engineering of To-day."

along the other line. That is a simple instance which will make the idea of the thing plain, but in a cabin of any size the levers are interlocked in a most complicated manner.

The actual mechanism by which it is done is, however, very simple. Placed in some convenient position near the row of levers is a locking trough. This is a piece of iron, with a number of grooves cut in it after the manner shown in Fig. 29. There are several grooves running the whole length, and still more running across. In each of the cross-grooves there slides a smooth, flat bar of steel, one of these "plungers," as they are called, being con-

Fig. 29. This represents a fragment of a "Locking Trough," which has saved innumerable lives.

nected to each of the levers by a kind of hinge joint. Thus, whenever a signal or point lever is pulled, the plunger attached to it has to move too, or if it cannot be moved the lever cannot be moved either.

Now each plunger has, cut in its edge, one or more notches, the purpose of which is to lock it in certain positions. A reference to Fig. 30 will help to make this clear. There I have shown three plungers, and I will ask you to assume that they are placed in three of the cross-grooves of a locking trough, like that illustrated in the previous figure, and that each of them is hinged to a signal lever. You will also notice two little objects with rounded ends marked locks. They also are little flat pieces of smooth steel, like the plungers, and they are placed, in the long grooves, between them.

Now imagine that plunger No. 2 be pulled, by the action of the lever to which it is attached being pulled

to lower the signal. It will push lock No. 1 into the notch in plunger No. 1 and hold it there, as you will see by Fig. 31. Thereby plunger No. 1 is locked fast, and the lever to which it is attached cannot be operated. As soon, however, as No. 2 is put back to normal then the lock will be able to slide into *its* notch, and No. 1 will be free ; for it will, if pulled, simply push the lock out of the notch in itself and into the one in No. 2, which will be just opposite. Then No. 2 will be locked until 1 is put back

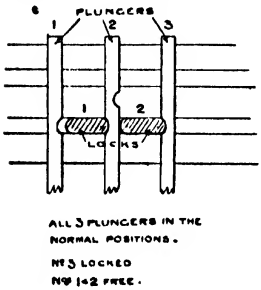


Fig. 30.

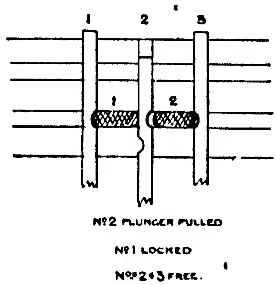


Fig. 31.

Here we see the beautifully simple apparatus whereby the signals are interlocked.

to normal. Thus those two levers are interlocked, and though either can be pulled at will, *it can only be one at a time.* To illustrate the principle a little further I have added the third lever, and you will notice that its signal cannot be lowered until No. 2 has been moved ; then No. 2 will be locked by it, and cannot be put back to normal until No. 3 has been restored.

This principle can be carried to almost any extent, and the beauty of it is that no matter how complicated may be the system of interlocking among a large number of levers, as soon as the system has been embodied in the

apparatus it becomes as simple and unerring in its action as any human device can ever be.

And now we can pass on to a newer invention, which embodies a refinement of the above, which, as a piece of mechanism, is very pretty.

I must first explain that, owing to the great amount of traffic at some points on modern railways, the labour of moving the levers is very severe, particularly when the points and signals are at some distance from the cabin. This causes a larger number of cabins to be needed at busy centres than would otherwise be required. To overcome this, systems have been invented in which the signalman only controls the signals and points, while the actual work of moving them is done for him by some form of power. Compressed air, electricity, and hydraulic power are all employed in various parts, and the little mechanism which I am going to describe (Fig. 32) is part of a compressed air or pneumatic system.

The communication between the cabin and the signal is not a wire, but pipes, and on the signal there is fixed a little pneumatic motor, really a small cylinder like that of a steam engine, with a piston inside it. The familiar lever gives place to a small iron slide which slides in and out of the frame in which it is fixed, as the drawers in a cabinet slide in and out. At one end of this "lever" there is a wooden knob for the man to take hold of, and when he wishes to lower a signal he places his hand on the proper knob and pulls it towards him, an action which takes scarcely any force at all.

The pulling out of the slide moves a valve in principle like the slide valve on a steam engine, except that there is nothing equivalent to the steam chest, but instead there

is a spring (not shown in the diagram), which keeps the valve down on the valve face. That connects the air-supply pipe to the pipe marked A on the diagram, which conveys air to the under side of the piston in the motor. The piston is thereby forced up, and the signal arm pushed down. When the time comes to put the arm back to danger the signalman simply pushes the slide in again, moving the slide valve back to its other position, in which it connects the air supply to pipe B and thereby presses the motor piston down, the same action uncovering the end of pipe A and letting the air from under the piston escape to the open air.

And that brings us to the cleverest part of the whole affair. The slides are all interlocked in exactly the same way that the levers are in an ordinary hand-worked system, but the interlocking is in this case made more perfect. You will remember that in the example described just now we saw two levers so arranged that when one was in the safety position the other was locked at danger; but as soon as the first was restored to danger the second was freed, so that it in turn could be put to safety. Now suppose that something happened, for example, that something fell upon the wire connecting the first lever to its signal so that when the lever was restored to danger the signal itself remained at safety, then the second lever would be unlocked and the second signal could be put to safety. Although the interlocking prevented both *levers* being at safety at the same moment, there is just the possibility with a hand-worked system that both *arms* might be at safety together.

In the pneumatic system, when the man pushes the islde in, to put the signal back to danger, it will not go

quite in. He may push with all his might, but he cannot do it. A glance at Fig. 32 will show you why. A pin which slides in the slot in the slide will come up against a "shoulder," which I have distinguished by the letter X. The slide will by then have moved sufficiently, however, to let the air into the upper part of the motor cylinder, so that the air can pass along pipe B to press the piston down and put the arm to danger. When the piston reaches its lowest position, and when therefore the

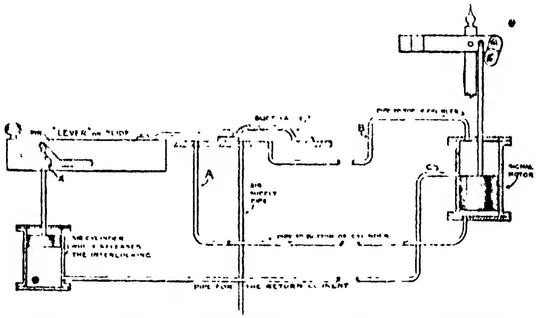


Fig. 32. Diagram showing how signals are worked by compressed air. One of the latest devices to ensure the safety of railway passengers.

arm must be up, *right up*, the piston just uncovers the end of the pipe C, through which the air passes to another cylinder placed under the slide. The piston there is therefore pushed upwards, and the pin in the slot, which you have probably noticed by this time is connected to the piston rod, is pushed up the slanting part of the slot. That causes the slide to be moved automatically its full distance to the right, for observe, the action of the pin against the shoulder prevents the signalman from pushing the slide right home, but it does not in any way interfere with the vertical cylinder doing it.

Now please notice this. It is the last little movement of the interlocking plunger which unlocks the other signal. That can be seen in Fig. 30. That last little movement cannot occur until the "lever" is pushed right in. That cannot happen until the return current comes along the pipe. And the return current cannot enter the pipe until the signal arm has actually gone to danger. Therefore the other signals are not unlocked until the signal arm has actually gone to danger, and the possibility of two conflicting signals being lowered together, remote though it be in the hand-worked system, is absolutely removed in the pneumatic system.

In "Engineering of To-day" I have described, at some length, the methods by which on some lines the trains themselves work their own signals, by electrical arrangements called "track circuits," and I shall refer again to the track circuit in the next chapter; but I should like to describe here the very interesting piece of mechanism whereby the electric current controls the compressed air which actually works the signal arms. By way of introduction, however, I ought to say this much. The line is divided up into lengths, and as soon as a train enters one of these lengths, or "sections," it puts the signals behind it to danger. There they remain until it has passed out of that section into the one further on. There is normally a current of electricity flowing from the rails to the signal and that causes the signal to remain at "safety"; but as soon as the train enters the section it diverts that current, and so in effect cuts it off from the signal, which forthwith goes to danger. The question is how a feeble current can thus control a supply of compressed air sufficiently powerful to operate full-sized railway signals.

Fig. 33 is a diagram which shows how it is done. The feeble current from the rails comes along wires to the signal, and there passes through a small electro-magnet, A. This forms part of what is called a relay, an appliance by which a feeble current is able to control a stronger

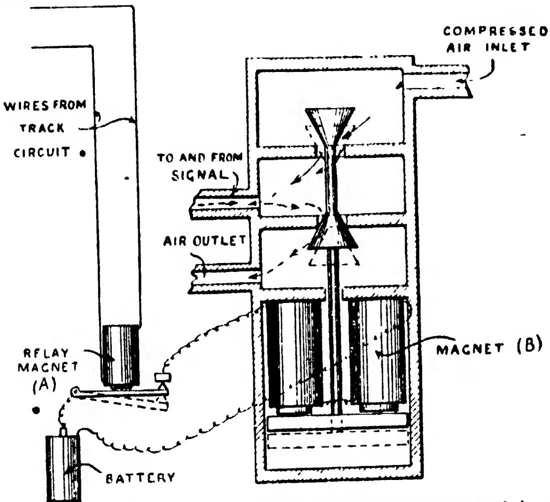


Fig. 33. An ingenious valve, by which trains are able to operate their own signals. In the position shown the signal will be down (at "safety"), but when the current from the track circuit ceases the moving parts will take up the positions shown by dotted lines, and the signal will go to "danger." (The full-line arrows show the course of the compressed air going to the signal, the dotted arrows the course of the air when escaping after it has done its work.)

one. It consists, in this case, of a little arm, which is attracted and lifted up by the magnet when current is passing, but which drops of its own weight when the current stops. When lifted it makes a contact and permits the stronger current to flow, but when down the contact is broken and the stronger current is stopped.

This relay is shown to the left of the diagram. To

the right is the valve itself. This consists of a metal case, with what we might term two floors inside it, each with a hole in the centre. Then there are two conical plugs, connected together by being fixed on one " stalk." Their distance apart is such, that if the pair be in one position the upper hole is stopped, but a slight raising of them both opens that, and instead closes the hole in the lower " floor." The stalk is, moreover, continued downwards, and at its lower end there is a cross-piece of iron, while just above this cross-piece there are the two poles of an electro-magnet. When this magnet is energized by the passage of current through its coils, the cross-piece is raised, carrying the stalk and plugs with it, so that the lower hole is closed. When the magnet drops it the converse happens and the upper hole is closed. It is the stronger current from a battery close at hand which passes through this magnet, but it is controlled by the relay, so that it starts and stops just as the feeble current from the rails does. In fact, it behaves just as it would do if it came direct from the rails and were itself controlled by the train.

So much for the electricity. Now let us turn to the compressed air. This enters the valve through the pipe on the right; it passes to the cylinder which operates the signal arm, through the upper one on the left, while, after it has done its work, it can escape to the atmosphere through the lower one.

The normal state of things is with current flowing. Therefore the cross-piece is held up and the upper hole is open. Air entering the valve then passes through that hole to the middle compartment and out to the motor, which pulls the arm down to the safety position (this state of affairs is shown in full in the diagram).

Presently a train enters the section and the current stops, so far as the signal is concerned. Then the position shown in dotted lines is brought about. The upper hole is closed and the compressed air thereby shut off. The lower hole is, on the other hand, opened, and so the air in the motor can return and escape through the outlet. Then the arm, which is weighted, so that if left to itself it goes to danger, being deprived of the pneumatic force which was holding it at safety, goes to danger and remains there.

This apparatus is so simple that it is almost impossible to see how it can ever get out of order, and if it did, it would certainly have the effect of putting the signal to danger. If the current fails it goes to danger. If the plugs were to stick they would be almost certain to do so in the "dotted" position, for in any other position gravity is trying to operate the valve. There are no springs, but, wherever an action is required, such as is usually performed by a spring, as in opening the relay, gravity is called in to take its place, and the arrangement has this great advantage that, while a spring may break or weaken or stick, gravity always remains the same. In short, this apparatus is an almost perfect example of what an automatic device should be, for it may be safely trusted to do its work without attention, and if it should err at all, it will err on the safe side.

Up till a few years ago the great city of London possessed an underground railway which, although in its time it had been quite one of the wonders of the world, had lagged somewhat behind the times. Then some enterprising men from both sides of the Atlantic took it in hand, and turned it into one of the most convenient

and efficient systems in the world. From the passenger's point of view, one of the most useful features of the new conditions is an indicator on each platform which tells him where the next train is going to, and the second and third likewise. He sees there the names of the stations at which the various services terminate, such as Ealing, Richmond, or Wimbledon, and also the words Inner Circle, to denote those trains which do not terminate anywhere, but go on round and round the endless line known by that term. Then, against three of these, there are always to be seen illuminated numbers. Suppose there is 1 against Ealing, then everyone knows that the next train which arrives is bound for that place. If there happens to be 2 against Wimbledon, a passenger for a station on the Wimbledon line knows that his train will be the second one in. Someone waiting for a train on the Inner Circle may, in like manner, learn that his train will be the third, while an unfortunate passenger, who sees no number against his destination upon the indicator, knows that he will have to wait until at least three trains have come and gone. As soon as the first train indicated has come, and is going out of the station, the numbers mysteriously change. Assuming the sequence is as I suggested above, the 1 will disappear from Ealing, the 2 against Wimbledon will change to 1, and the 3 against Inner Circle will change to 2, while the figure 3 will appear in a new position altogether, say against Richmond. So, whenever you go on the platform you can see at a glance where the next three trains are bound for, and can pick out the one which interests you.

How this great convenience works has puzzled many a waiting traveller, and I venture to think that its inner

mechanism may be interesting, too, to others, who have only heard of it and wished that its silent services were available on lines which they use. Therefore I am going to attempt to describe it. I say attempt, for it is not an easy thing to make clear upon paper. Yet in working it is very simple and sure. It seldom goes wrong, and needs little attention.

The essence of the idea is what is called the "Magazine Train Describer." On all railways there are instruments by which the signalman at one cabin can tell his colleague in the next what kind of train it is which is approaching him. When, as is generally the case, there is only one train at a time between the two signal cabins, this is quite easy. The one man can simply telegraph on to the next cabin as the train passes him. When, however, there are automatic signals, there may be many trains at the same time in the space between two signal cabins. In the case of the Metropolitan District, there are sometimes as many as twenty-five trains between the two signal cabins at Mansion House and South Kensington respectively. They are kept a respectful distance apart by the automatic signals, but these have not the intelligence to pass on the descriptions of the trains to one another, as signalmen would do in a non-automatic system. The man at one of these cabins must send a message to his colleague at the other every time he sends a train forward, and that message may reach the latter while there are still twenty-four other preceding trains to come in. It would, of course, be impossible for any man to remember a continually changing list of twenty-five trains, so an ingenious device has been invented whereby the destinations are received

at the signal cabin, but are not at once communicated to the signalman. Instead, they are stored up until he wants them, and then they are ready to his hand.

At the sending end there is an instrument something like a clock, only, instead of figures, there are round the dial a circle of fifteen smaller circles, each marked so as to correspond with the "headlights" on the trains, which indicate to the staff their destinations. In the centre there is a single hand, or pointer, with a knob, by turning which it can be set to point to any of the fifteen smaller

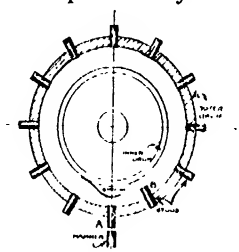


Fig. 34. Diagram showing the working of the Westinghouse Magazine Train Describer, the remarkable apparatus which controls the destination indicators on the District Railway (London).

circles. When a train leaves, the signalman turns the pointer to the small circle which corresponds with the destination, and then pulls over a lever at one side of the instrument. That is all he has to do, and he then leaves the matter until he has another train going forward, when he describes it, too, in the same way.

At the receiving end there is an apparatus somewhat like the "Annunciator" used with an electric bell at hotels and such places, where one bell can be rung from many rooms, and the particular room is indicated by the falling of a disc at a tiny window marked with the name of the room. There are fifteen of these little

windows to correspond with the fifteen different destinations and the approaching train is described by the appearance of the disc at the proper window. As each train leaves him, then, the signalman presses a push or plunger, and the description of the departing train disappears, that of the next one to approach taking its place, so that there is always exhibited before the signalman's eyes the description of the next approaching train. That particular description was sent from the other end several minutes before, but it does not appear until it is wanted, and when it does appear there may

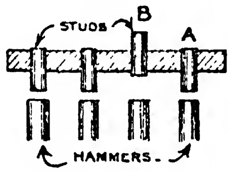


Fig. 35. A section through the large drum showing how the four hammers can drive in the four studs.

be twenty or so more descriptions already received at the cabin and stored up, in the instrument, waiting for the time when they are needed.

Now how is this done? Needless to say, electricity has much to do with it, but it is really the ingenious mechanism rather than that subtle fluid which is the secret. The idea underlying this mechanism I have tried to illustrate in the diagrams Figs. 34 and 35, which, I must ask you to remember, are not intended to be accurate drawings of the apparatus, but simply diagrams to show the principle. The outer circle in Fig. 34 is intended to represent a hollow drum, mounted so that it can rotate upon its centre. Around this drum there are holes, in which small metal studs are fitted. Normally

the studs project outside the drum, as the one marked A, but a small hammer is able to strike upwards and drive a stud in so that it projects inwards, in the position shown at B. Inside the first drum, suppose that there is a second one, carrying a metal spring or finger, which, when the small drum is turned, will just "wipe" the end of a pressed-in stud, but will clear a stud in its normal state. Then imagine that, instead of there being one stud at A and one at B, each of these is the end one of a row of four, and the spring and hammer, too, are each the end one of four, then we shall have a good idea of the apparatus.

There are four wires passing from the sending instrument to the receiving one, and for each different destination the sending instrument sends current along one or more of these wires. For example, current along the first wire indicates one destination, along the second wire another, along the first and second simultaneously another, and so on. With four wires used singly, or in combination, it is possible thus to make fifteen different signs. Each of these currents operates a separate hammer, and so if, for example, currents flow along wires two and four, hammers two and four will drive in studs two and four in the row which is then above them. At the same time, the large drum (and the small one with it) will move one step, so that the next sign which comes along will be recorded by the hammers on the next row of studs. And so it will go on, the signals as they come in deing recorded upon the consecutive rows of studs.

The incoming signals, it will be noticed, turn both the drums together, but the pressing of the plunger, by which the signalman brings the signal into his indicator so that he

can read it, turns the inner drum without turning the outer one. Thus every time he presses his plunger the springs come into contact with a fresh combination of studs. The studs are themselves alive with current, so that this has the effect of producing in the wires, to which the springs are connected, a series of currents, corresponding exactly with those which brought the description of the train from the other cabin. These currents are led to a small apparatus called a "Combinator," which causes each combination to reproduce on the "Annunciator" the correct indication. Thus we see how the first set of currents (from the other cabin) record themselves by pressing in different sets of studs, the studs, in turn, producing, when required, similar sets of currents to the first, which give the visible indication.

At each station where there is no signal cabin, there is one of these describers to control the destination indicators. It is just the same as those in the signal boxes, except that it has three sets of springs on the inner drum instead of one, and the electrical wires are so arranged that the first set of springs illuminate the figure 1 against the destination indicated by the studs which they touch, the second set of springs the figure 2, and the third the figure 3. In this case, too, the operation which the signalman in the cabin brings about, by pressing the plunger, is performed by the passing of the train itself. Thus each train, in effect, announces to us what the succeeding trains will be.

There is an invention, in connection with the railway, which is quite recent, and is, too, of such great importance that it ought to be described here. As, however, this chapter is already rather lengthy, that subject will be reserved for the next.

CHAPTER XI

A GREAT SAFETY DEVICE

WITHIN the last few years there has come into use an arrangement, which is of the greatest importance to the safety and convenience of the public who travel by railway. I refer to the " track circuit," and I do not hesitate to say that it ranks with the block system and the system of interlocking the signal levers as the greatest of all inventions connected with the safety of railways.

Automatic signals, to which reference has just been made, would be almost impossible without the track circuit, and as a safety device purely and simply there is a vast field for its use in which it is practically without a rival. It is essentially an electrical contrivance, yet its perfect reliability consists in the ingenious mechanical arrangement of its parts.

Briefly, a track circuit is this. Each block section, that is, each section of line in which only one train is permitted at a time, is electrically separated from the adjoining sections by insulating joints in the rails. Then current from some convenient source of supply is led to one rail: thence it goes to the signal cabin, or if the signals are automatic to the signal itself, whence it returns to the other rail, and through it back to the source of supply. The actual track rails upon which the trains run thus form a part of the circuit. This explains the name, track circuit.

What I have just described is the normal state of affairs, and the flow of current to the cabin or signal, as the case may be, permits the signals at the entrance to the section to be lowered. The moment, however, that a vehicle of any sort enters the section, the current is provided with a very easy path through the wheels and axles from one rail to the other. The wheels and axles are, of course, very massive, and made of a good conducting substance (namely steel); and, moreover, the weight of the vehicle ensures their being well pressed down upon the rails, so that a good contact is a certainty. Thus we are able to rely absolutely upon the fact that the wheels and axles will form a much easier path for the current than its normal path, and that the current will therefore choose it of the two. This method of diverting current from one circuit by providing it with another much easier one is technically known as "short-circuiting."

The presence of a single pair of wheels in any section, therefore, short-circuits the current and deprives the signal box or signal of its supply, and things are so arranged that when that occurs the signals go to danger, or if already in that position are securely held there.

That is the fundamental idea of the track circuit; but such a simple arrangement, though good, has not the absolute freedom from the possibility of failure which we must demand in an apparatus on which the lives of many people may depend. This is particularly so when the trains themselves are operated by electricity, for the presence of the traction current in the rails or near them provides just a chance that extraneous currents might leak into the system, and so cause it to signify safety when, in fact, there was danger. This risk is, however,

entirely overcome by means of a system of relays, which I will now explain.

A relay, as is well known to all who are interested in telegraphy, is an appliance by which a feeble current controls a stronger one. It consists of an electro-magnet, which becomes energized whenever the feeble current passes through it, and which, when thus excited, pulls into contact two objects which thereby complete a circuit

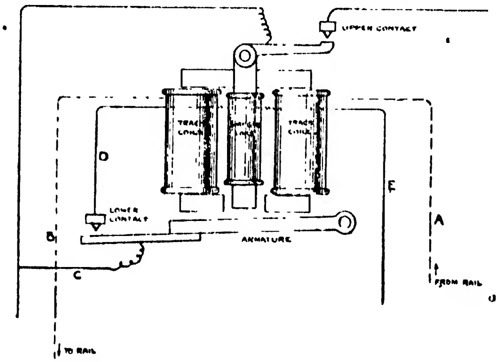


Fig. 36. This shows the working of "Brown's patent Relay," an ingenious electro-mechanical device, by which the trains may *safely* be left to control their own signals.

for the stronger current. Fig. 36 will help to make this clear. There we see an electro-magnet with two coils of wire very similar to the magnet which works an electric bell, only the coils are a little wider apart. If current comes along the wire shown by the dotted line A, passes through the coils marked "track coils" (so called, as we shall see presently, because they are directly connected to the track circuit), and then back through wire B, the magnet will be excited and will pull up the little iron lever, which is termed the "armature," and so close

the "lower contact." When that current stops the armature will be released and will drop again.

Now you will observe that between the track coils there is another coil, which I have marked "swinging coil." This has nothing to do with the magnet which I have been speaking about; in fact, it is another magnet altogether, and it derives its power, when it has any, from the current flowing along the wires D and E. It is a fairly well-known fact, but I will just remind you of it here, that two magnets do not attract each other in quite the same way that a magnet attracts a piece of iron. Every magnet has two ends, one of which we call the North Pole and the other the South Pole. Both poles attract plain iron equally, but a North Pole only attracts a South Pole of another magnet: it repels a North Pole. It is the same with South Poles, which attract North Poles, but repel poles like themselves. The rule is, tersely, that unlike poles attract, while like poles repel each other. In the case of electro-magnets, which pole is North and which South depends upon the direction in which the current is circulating in the coils. In these two magnets the one which has the two coils has its poles pointing downwards, so that one is to the right and one to the left. The magnet with the one coil, being of a different shape, has one pole at the bottom, between the two poles of the other magnet, and its other pole at the top. Thus whenever current is passing through both magnets the swinging magnet will be pulled to one side or the other, for its lower pole will necessarily be attracted by one pole of the track magnet, and repelled by the other. It will only hang vertically, as shown in the diagram, when no current is passing through it. Moreover, if current

be passing through both magnets and the swinging magnet be thereby pulled to the right, for example, if the direction of one of the currents be changed the poles of that magnet will be reversed, and then the swinging magnet will be forced to the left.

The swinging magnet, when pulled to the right, closes another contact marked upper contact, so that this particular appliance is really two relays combined into one. The first is closed by a current through the track coils, and it will be operated in whatever direction the current may be flowing. The second is closed by current flowing through the swinging coil and it is closed only by current flowing in one particular direction. The contact will be opened if the current stops or the direction be changed. And now we can follow the action right through.

When a train leaves the section and so cuts off that easy path through its wheels and axles the current finds its way from one rail through wire A to the track magnets. Passing through them it goes via wire B back to the other rail. The effect of that is to energize the track magnet, lift up the armature and close the lower contact. This current is but a feeble one, from 2 to 4 volts, little more than that of the current which works the domestic electric bells. The closing of the lower contact, however, sets going a much more powerful current of about 60 volts through wires C and D, the swinging coil and wire E. The swinging magnet is thereby energized and swings to the right, thereby closing the upper contact. That again permits 60-volt current to flow, this time to the signal cabin, or to the signal itself as the case may be, and it is only when this last current is flowing that the signal

can be down. Any stoppage of that current instantly puts the signal to danger.

I must now ask you to turn to the next diagram (Fig. 37). We have just seen how, in order to give a "line-clear" indication, the 2–4-volt current must first be flowing (and flowing fairly strongly, too, for it has to lift the weight of the armature), then it must close the lower contact, so as to energize the swinging magnet and close the upper contact. Any weakness or failure, be it noted carefully, puts the signal to danger. Then you will observe by this last diagram that there are two of these relays, one at each end of the section, and to give a line-

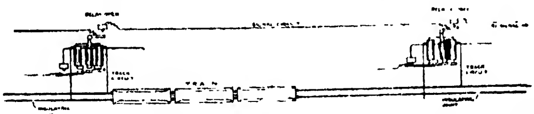


Fig. 37. This diagram shows how the signal current has to pass through *two* relays before it can lower the signal and *either of them can stop it.*

clear indication they must *both* be operated. Thus the safeguards against failure which I have just enumerated are duplicated.

To avoid too many complications I have not shown where the various currents come from. I have contented myself with indicating their courses through the relays; but the various wires are so arranged that the only possible circumstances which can exist when a train is in the section are these:

(*a*) The current completely short-circuited. Result—both relays open and the signal circuit broken at two points.

(*b*) One relay short-circuited, the other energized normally by extraneous current. Result—signal circuit broken at one point (as shown in Fig. 37).

(*c*) One relay short-circuited, the other energized in the opposite direction to the normal. Result—signal circuit broken at two points.

(*d*) Both relays energized, one normally, the other reversely. Result—signal circuit broken at one point.

All the conditions except (*a*) would be the result of outside electrical influences, from the traction current or some other source. They exhaust every possible condition, and with every one of them the signal circuit is broken at one point at least, thereby setting the signals to danger.

There is no such thing in this world as a perfectly infallible machine, but here it would seem as if we have an arrangement which, if it cannot be relied upon absolutely never to go wrong, can certainly be depended upon to err, if at all, on the safe side.

CHAPTER XII

THE ADJUNCTS OF THE MODERN BOILER

Where there are a number of large boilers there are usually a number of interesting appliances working in connection with them. Mostly these are to utilize some of the heat which would otherwise be wasted, and so reduce that enormous loss to which reference has already been made.

Of these the superheater is one of the most valuable. Steam, you must understand, is really a gas, and it will expand if it be heated just as air or any other gas would do. That expansion will, of course, increase its pressure; but what is perhaps more important, the extra heat thus added to the steam, over and above that which was required to convert it from water into steam, it is able to part with before it begins to condense.

Steam which has thus been given extra heat is called superheated, while steam just as it arises from the water is called saturated steam. On its journey from the boiler through the pipes to the engine it is somewhat cooled; for, of course, some heat is always escaping from the surface of the pipes into the air, and so the pipes themselves must always be slightly cooler than the steam. They are usually covered with a thick covering of non-conducting substance, but that does not entirely prevent the escape of heat.

The steam, therefore, tends to condense as soon as it passes from the boiler into the pipes; indeed, were it not for the latent heat, which saves the situation as described in a previous chapter, the steam, as soon as it passed from the heat of the boiler into the slightly cooler pipes, would collapse into water instantly, and so all pressure would be lost and the engine would not be worked. In fact, the steam would never reach the engine at all. I actually know of a case in which steam was to be used for heating a building at a considerable distance from the boiler, and the pipes being too large and insufficiently covered the steam never reached the building at all. The largeness of the pipes caused the flow of steam to be slow, and during the passage it lost sufficient heat to be entirely condensed. That, of course, was simply an exaggerated example of what always occurs when saturated steam passes along a length of pipes. With superheated steam, however, it is different. The extra heat must be got rid of before condensation can begin. The steam naturally contracts as it loses this "superheat," and so loses pressure slightly; but it does not suffer that quick contraction which takes place the moment steam falls in temperature below the boiling point which corresponds to its pressure.

That, then, is the primary reason for superheating the steam, to minimize the loss which would otherwise occur through the steam being condensed through contact with the slightly colder surface of the pipes and the cylinder itself.

The apparatus is generally arranged so as to use heat which would otherwise be wasted. One kind of superheater is composed of a number of steel tubes bent into

a shape roughly resembling a letter U. The ends of the pipes are connected to two steel boxes in such a way that the steam enters one box, passes through the pipes, and emerges into the other box. The superheater is placed in that downward flue at the back of the boiler, which has already been referred to by its technical name of " downtake." It is the flue which, you will remember, takes the hot gases down from the ends of the cylindrical flues into the brick flue under the boiler.

The steam, as it leaves the boiler, goes to one of the boxes, through the pipes, and then away from the second box to the engine. The tubes are naturally very hot, being in the direct course of the hot gases soon after they leave the fire, and so they heat the steam above the semperature at which it leaves the boiler. A superheat of 100 degrees is about the usual thing, but there are some cases in which even greater heat is imparted to the steam in this way. And this extra heat, you will observe, is obtained practically for nothing. It is taken from the gases in the course of their journey through the flues, and so is deducted from that amount of waste heat which the gases eventually carry away with them up the chimney.

The practice of superheating the steam was suggested as long ago as 1857; but it was not adopted to any extent then, mainly because of the difficulty of obtaining lubricating oil for the piston, which would not be destroyed by such a high temperature. The manufacturers of lubricating oil have entirely overcome that difficulty, but even now there are many engineers who fail to realize the advantage of this really valuable invention.

Another quite modern innovation in the boiler-house is the mechanical stoker. With this apparatus the at-

tendance on the boilers is reduced to a minimum. The coal, which is generally stored in bunkers in the upper part of the boiler-house, falls down large iron pipes to the stokers, which feed it into the furnaces not only with less labour, but more effectively than any human stokers can do.

It is not realized by many what skill is required to stoke a large furnace properly. The fuel must be spread in an even layer all over the floor of the furnace. If there be any gaps, any parts, that is, left uncovered with fuel, cold air will rush through them without assisting in the process of combustion, but simply lowering the temperature of the hot gases, and so reducing the efficiency of the fire. Every particle of air, indeed, which is drawn into the fire at all must be made to pass into the fire and do its share of burning, produce its own share of heat, and pass on not as air merely, but as hot gas from the fire. If you observe a stoker stoking his fires, you will notice that he gives his shovel a dexterous little twist just as he throws in the coal. That is the reason; he is scattering it so that the whole fire shall be even and continuous.

He must see to it also that there are no large quantities of black coal anywhere. Coal, when it first burns, gives off tarry vapours which form smoke, and if a lot of coal be thrown carelessly into a fire the result is smoke. This passes up the chimney, and if it be in a populous district possibly brings down the local authorities with a summons for emitting too much smoke and spoiling the public's atmosphere. If, however, the coal be put in in small quantities, and the new coal always at the front of the furnace, the vapours which would otherwise pass off in the form of smoke having to pass over the whole length

of the fire are burnt up and destroyed. Moreover, another point in connection with "hand" firing is this. Every time the furnace door is opened to put in fresh fuel cold air rushes in, and so the temperature of the fire is reduced.

Now let us see how the mechanical stoker overcomes these difficulties. In the first place it never opens the furnace door, and so never lets in blasts of cold air. It always feeds the coal in the full width of the furnace, so that it is always covered, and finally it is continually at work feeding the fuel in tiny quantities and always at the front of the furnace. It moves the whole fire backwards continually, the new coal being supplied at the front and the ash falling off the grate at the back. Thus the smoke from the new fuel is made continually and in small quantity, and as it always has to pass over the whole length of the hot fire it is effectually consumed, and no smoke reaches the chimney.

There are two well-known types of this apparatus. Both are remarkably simple. In one there is a slit in the front of the furnace, and in this slit there works a flat, blunt-ended object, which we might liken to a small drawer. This drawer-like part is continually moving in and out a few inches, and every time it comes out a little coal falls down behind it. Then every "in" stroke pushes this small quantity of coal into the fire.

The grate itself is composed of firebars, which are capable of moving to and fro. At one moment every alternate bar moves an inch or so towards the front of the furnace. A moment later the other half of the bars move to the front. A moment later still they all move back together.

This has the effect of preventing the fire from sticking

to the bars and also of *gradually carrying the fire to the back of the grate, for half the bars (alternate ones) moving together have little or no effect in moving the fire, but* when they all move backward together the whole fire goes too. The speed at which the fire is thus moved backwards is so arranged that by the time the coal reaches the further end there is nothing left of it but the ash.

The other type of mechanical stoker consists of a "chain grate." Imagine a number of large bicycle chains set side by side passing over two rollers, instead of two chain wheels, so that all the chains can be carried by the same two rollers. The upper surface of the chains might then form a "chain grate." Such a contrivance can be well placed under the fire in a water-tube boiler, and then, when the rollers are turned round, the grate itself gradually moves backward, carrying the fire with it to the back, and drawing in a thin, even layer of coal from the hopper on the front of the boiler.

When the gases leave the flues of the boiler they still possess great heat. Part of this is utilized in the chimney, for, of course, it is the lightness of the gases in the chimney, due to their heat, which causes the draught which makes the fire burn. The heat in the chimney is therefore not entirely useless, but it might, nevertheless, be put to better use. If it could be made to generate more steam it would be doing more valuable work than it does at present; but the difficulty is to get it to do that. There is a limit beyond which we cannot make the heat do work. For example, if we are working a boiler at a pressure of 160 lbs. the water will have to be kept at a temperature of 370 degrees. The hot gases from the fires pass along the flues, making the water hotter as they pass, but, of

course, getting colder themselves. When they get down to 370 degrees it is no good taking them round any more flues, for the water in the boiler is already as hot as they are, and, as we all know from common experience, you cannot heat a thing with something no hotter than itself. Therefore we cannot heat the water in the boiler beyond a certain point with the hot gases from the fires, although they may still contain a large quantity of heat.

We can, however, use them to heat the "feed-water," the water, that is, with which we feed the boiler, and for this purpose an apparatus called an economizer is often installed.

In the large flue through which the hot gases pass, on their way from the boiler to the chimney, are placed a large number of vertical cast-iron pipes. The hot gases have to find their way past and amongst these while the feed-water is flowing through them. A certain amount of soot is deposited by the gases upon these pipes, and so on each one there is fastened a small, cage-like object which can slide up and down. A chain is attached to each of these scrapers, for that is what they are, and a simple mechanism above, driven by an electric motor or a small steam engine, spends its time alternately hauling the scrapers up the pipes, and allowing them to slide down again. This keeps the pipes clean and free from soot. Soot, of course, is a very bad conductor of heat, so that if it were allowed to accumulate the efficiency of the economizer would be largely impaired. Indeed, it would cease to "economize."

In the up-to-date power station everything is carefully watched to see that no energy of any sort is wasted if it can be prevented. The fire itself, therefore, is subject to

continual testing to see if it is working properly. This is done by testing the waste gases as they pass to the chimney to see if they possess the right amount of carbonic acid.

If combustion were perfect there should be 21 per cent of carbonic acid in the waste gases. In actual practice there must be a little less than this; but there ought to be at least 15 or 16 per cent, whereas sometimes there is as

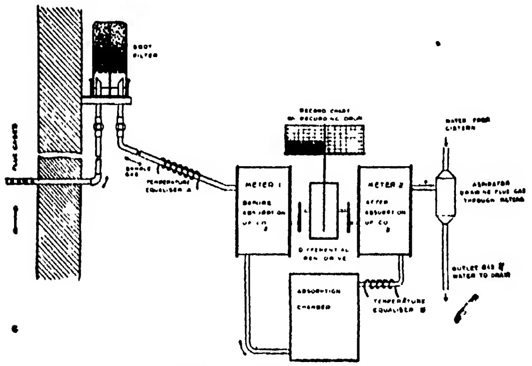


Fig. 38. This diagram shows the operation of an apparatus for telling how thoroughly the furnace fires are burning.

little as 5 per cent. That means that out of every 100 tons of coal burnt, 20 are wasted and might be saved. The advantage of watching the amount of carbonic acid is therefore evident.

An apparatus for automatically testing the gases is shown in Fig. 38. On the right there is an aspirator. This is a small closed cistern, which is periodically filled with water; when full the water inlet closes and an outlet opens. The water running out by gravity then sucks in gas until the cistern is full of it; then the water outlet

closes again, the aspirator is once more filled with water, while the gas escapes to the atmosphere.

The action of this aspirator, then, is to draw in, from the chimney and through the apparatus, at certain intervals, a sample of the gases in the chimney. It can be arranged to work 25 times per hour or any less number.

The gases first pass to a smoke-filter, to rid them of any smoke which they may contain. Then they go to meter No. 1, which is just an ordinary gas-meter. After passing through that they enter the absorption chamber, a vessel in which there is a quantity of lime. Now lime has a great affinity for carbonic acid, so that it absorbs it, and it is only the other gases (principally nitrogen) which pass to the second meter. The result is, then, that the whole of the sample passes through the first meter, but a less quantity through the second one, and the difference between them represents the amount of carbonic acid.

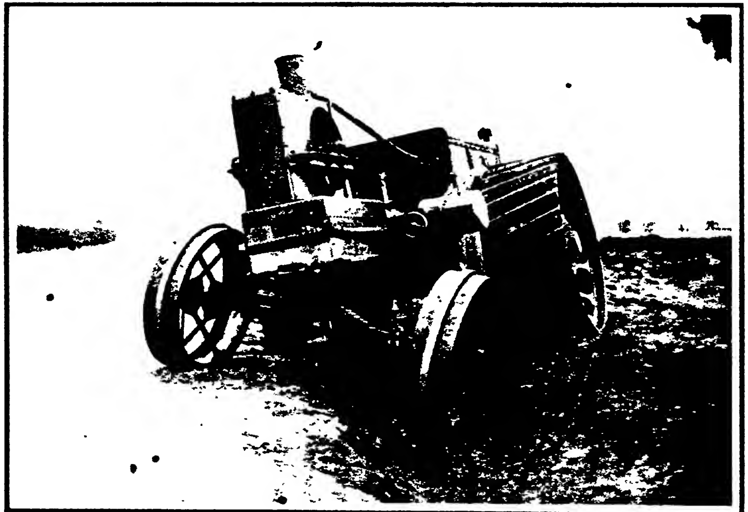
This is recorded upon a chart in a very ingenious way. The meters are made to turn two small tooth wheels just as they ordinarily would drive a pointer on a dial. Each of them turns its wheel an amount which is exactly in proportion to the amount of gas passing through it. The action of the first one raises a pen, but the second one counteracts it. If they both turned at the same speed the result would be that the pen would not move at all; but since the first one has more gas through it than the second it naturally turns a little faster, and so the united action of the two results in the pen being raised a distance which represents, exactly, the amount by which the quantity of gas going through the first exceeds that going through the second. In other words, the height of the line drawn by the pen represents the quantity of carbonic acid in the

sample of gas. After each sample has passed the pen returns to zero.

These lines are drawn upon a moving strip of paper, so that the result is to produce a number of short, parallel lines, each representing a sample tested. The paper is of such a width that if the proportion of carbonic acid were 100 per cent the line would reach right across it, and so the height of any line represents the percentage of that gas which was actually present. The strip is long enough for 24 hours, and it is divided up, by lines, into 24 parts, each of which represents an hour. Thus every day the engineer in charge of a plant can look at the diagram for the previous day, and if there are any evidences of careless firing he can tell at what time they occurred, and who was responsible.

There is one other interesting little feature in this appliance. The temperature of the gases naturally falls between the time when they enter the first meter and the time when they enter the second. The volume shrinks as well, and were nothing done to obviate it that shrinkage would be recorded as so much carbonic acid. Just before they enter either meter, therefore, the gases pass through a temperature equalizer. This is a series of tubes in contact with water, and in the first one the gases give up heat to the water, while in the second they get heat back from the water. Thus the temperature in both meters is about the same, and the serious error which would otherwise occur is avoided.

Where oil fuel is cheap it is sometimes used instead of coal; but in spite of its advantages it is not likely to displace coal, at any rate on land, except where oil is very plentiful. There are several ways of burning oil in a



By permission of] [*Messrs. Marshall, Sons & Co., Ltd.*

NOT A CATASTROPHE

This remarkable machine is a Tractor, driven by oil-power, made for drawing heavy loads through trackless country. It is here crossing a ditch just to show what it can do.

boiler. One is to force it with a pump through a fine nozzle, so that it enters the furnace as fine spray. Another, and perhaps the most usual way of all, is to blow it in with a jet of steam or air. A third way is to vaporize it by means of heat in a separate vessel, and let it enter the furnace in the form of gas.

On board ship this form of fuel has great advantages, for it has a much greater heating value than coal has, and consequently less of it need be carried for a voyage of a given length, and the awful labour of trimming the coal on the voyage and feeding it by hand into the furnaces is avoided.

In many towns the refuse from the domestic dust-bins is burnt, and although it is of poor heating value, since it can be got for nothing, indeed has to be burnt for sanitary reasons, what heat it does possess is often used for raising steam.

It is burnt in large furnaces of brickwork, and the hot gases are led away through a flue to a boiler either of the "Lancashire" or water-tube type.

Illustration Fig. 39 shows a section through the destructor furnaces of the Westminster City Council in London. There are six furnaces set in three pairs back to back, and the section shows one pair. The loaded carts back in and tip their contents straight into the furnaces. Some, approximately half, falls into one furnace and the rest into the other. The furnaces themselves are not special in any way, except that they are blown with a blast of air. You will observe the three flues in the brickwork under the furnaces; the smaller, outer ones are the "blast flues," and small passages lead from them to the ashpits of all the furnaces. Air is forced into

the blast flue, and so the furnace fires are fanned. The hot gases pass through other passages (which cannot be seen in the section) into the large central flue known as the main flue, which takes them away to the boiler. From time to time the doors at the sides are opened, and the ash and clinker are drawn out.

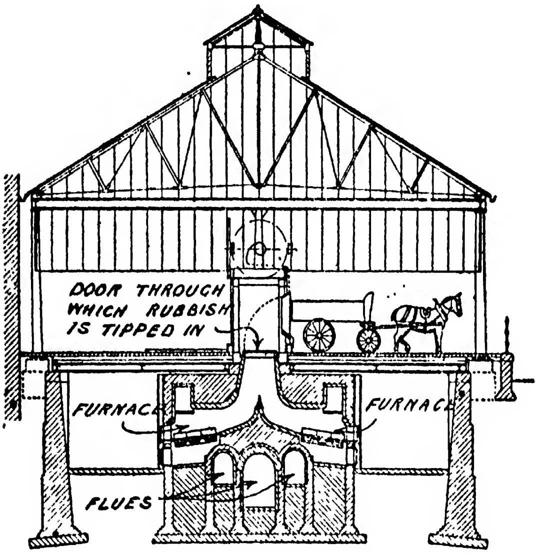


Fig. 39. How useless rubbish is turned into valuable power.

The hole through which the refuse is shot in needs to be a large one to take a whole cartload at once, and it needs, too, to be securely closed to prevent the escape of smoke and hot gases from the fires. This is effected by a large lid made of iron working on a hinge and balanced, so that little force is required to open and close it. All round the edge of the hole there is a gutter full of water,

and the lid has a rim which falls down, when the lid is closed, into the water, and so forms what is known as a water seal. The water makes a perfect joint past which no smoke can pass, and yet leaves the lid quite free so as to open and close easily.

The clinker, as the burnt refuse is called, comes in for many useful purposes. It makes very fair road material, if ground it can be turned into bricks or artificial paving-stones, and, suitably treated with tar, it forms good tar-paving. The heat generated is often used for driving the plant in connection with the conversion of the clinker into these useful products, or else for electric lighting, sewage-pumping, or some other municipal work.

That brings us to an important feature of many steam plants, the forced or induced draught. The purpose of the tall chimney is to create a draught to draw a copious supply of air through the fire, and so ensure rapid and complete combustion. Sometimes, as on ships, it is not convenient to have a tall chimney, and then the necessary draught is obtained in one of two ways, either by forcing air into the fire, or by sucking air through it. On ships of war the "closed stokehold" method is adopted. The compartment where the boilers are is sealed, so that it is perfectly airtight. Then fans above force air down into it, thereby giving the men a supply of fresh, cool air and also blowing the fires, for the only way of escape which the air has is through the fire and up the funnel. Another method is to force air into the ashpit under the grate. A third way is to put a fan in the flue just at the base of the chimney, and arrange it so that it draws air through the fire. This latter method is termed "induced draught."

Locomotives always use "induced draught," the waste

steam as it escapes from the cylinders shooting out of a nozzle directed up the chimney. The effect is to induce a draught of air up the chimney, and so to draw air through the fire.

Whenever there are long lengths of steam pipe, or any place in the pipe where water could lodge, such as a dip in the pipe, a steam trap is placed. There are numberless varieties of these ingenious contrivances; but they are all for the same purpose, namely to let out the water, but to close and keep the steam in as soon as all the water has gone. They are, too, almost all constructed on the principle which is illustrated by the one shown in Fig. 40. The

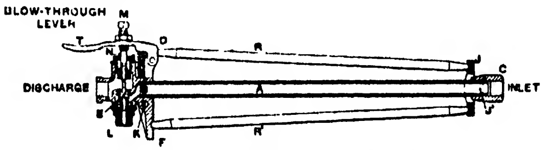


Fig. 40. A trap for letting the condensed steam out.

tube A is connected to the under side of the steam pipe, so that when there is only steam in the pipe the tube contains steam only, but as soon as water begins to accumulate it runs down and fills it. Now water produced by the condensation of steam is clearly cooler than the steam, and therefore, when the tube becomes filled with water, it contracts. The rods R and R¹ are, however, in contact with the air and removed from the influence of the steam and water, so that their length is not affected by the variation which tends to contract the tube. The contraction of the tube, therefore, causes the end of the rod R to press against the little cranked lever D, causing it to compress the spiral spring and open the valve E. The water then rushes out through the valve until it is all gone, then the

steam following, being hotter, causes the tube to expand again and so closes the valve once more. The handle T, you will observe, opens the valve if it be depressed, just as the contraction of the tube does. That is so that the apparatus can be tested by hand occasionally to see that it is clear and working properly.

The principle, you will notice, is that water is colder than steam, and therefore the former will cause a suitable metal object to contract and open a valve, the valve closing again so soon as the object expands again under the influence of the superior heat of the steam.

The most delicate, and in some ways the most beautiful, invention in connection with the steam boiler is the pressure gauge. There are two kinds of these, known respectively as the Bourdon and the Schaffer, both after their inventors.

The Bourdon gauge works upon a curious principle. If you take a curved metal tube and force some fluid into it under pressure, it tends to straighten out. With that clue I fancy that most of my readers will see the meaning of Fig. 41. The steam comes up the vertical pipe and enters the curved tube K. The pressure tends to straighten this out and so causes its end M to move, thereby pulling the little rod to which it is attached and turning the finger. The greater the pressure the greater the straightening, and therefore the greater the movement of the finger.

Fig. 42 shows the "works" of a Schaffer gauge. There the steam also comes up the vertical pipe; but it finds its way into the gauge itself barred by a metal diaphragm A, which you will observe is corrugated, so as to render it as far as possible free from the effects of the variations in

heat. The pressure acting upon the diaphragm bends it more or less, the amount of the bending varying according to the pressure. Whatever it may be, the bending is communicated by the rod C to the simple mechanism which moves the pointer and so indicates the pressure on the dial.

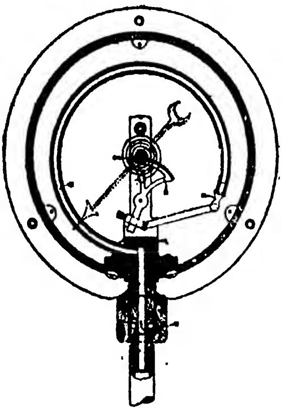


Fig. 41.

Section of the Bourdon pressure gauge. The pressure of the steam tends to straighten out the tube K and so moves M and consequently the pointer.

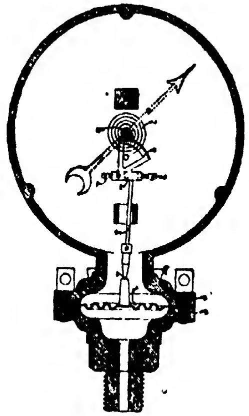


Fig. 42.

Section of the Schäffer pressure gauge.
The steam bends the diaphragm A more or less according to its pressure and so moves the pointer.

In both these cases only the inside of the gauge is shown; but in the actual thing itself there is a white-faced dial in front with the pressures marked in figures, so that the position of the pointer can be easily read off as so many pounds to the inch.

A pressure gauge is usually fixed not to the boiler directly, but at the end of a long, curled tube, sometimes only a plain U-shaped bend, but at others a complete

coil. The reason is interesting, as it illustrates the bad heat-conducting properties of water. The mechanism of the gauge is damaged, or, at any rate, rendered inaccurate by excessive heat. Therefore the steam itself must not come near it. The curled pipe, however, soon becomes filled with condensed steam, or, in other words, water. This water conveys the pressure from the steam to the gauge as effectively as if the steam penetrated to the innermost parts of the instrument; but it is such a poor conductor that it shields it from the heat. It loses its heat through the thin walls of the tube, and cannot itself conduct more to take its place from the hot steam of the boiler.

Before leaving this subject, another interesting little instrument, designed for use in the boiler-house, is well worth our notice. It is a meter for measuring the quantity of steam passing along a pipe. Fig. 43 is a composite kind of drawing, since it shows the lower part of this apparatus in section, while the upper part is shown whole. I think, however, it will not be difficult to understand. The steam enters the apparatus at the opening E on the left-hand side, and leaves it by the corresponding outlet on the right-hand side. Between the two it passes through the apparatus, and the quantity flowing is recorded by a pen on the drum F.

A little inspection of the diagram makes it quite clear that the steam, on entering, passes upward and then dives downwards through what looks like the spokes of a toy engine wheel. As a matter of fact, what looks like a little wheel is simply a light metal guide, intended to guide the wire *a*, on which is fixed the small disc *c*. Rushing downwards the steam pushes this disc before it, thereby making

a larger way for itself, for the cone-shaped cylinder in which the disc is placed is larger at the bottom than at the top. Therefore the lower down the disc is the freer passage has the steam past it, and consequently the more steam there is flowing through the apparatus

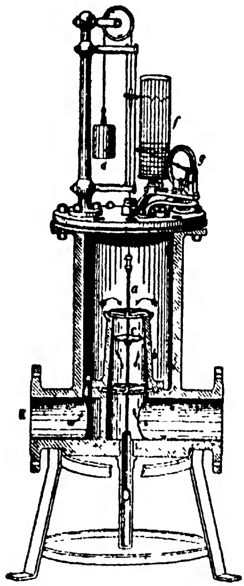


Fig. 43. A meter that measures the volume of steam that an engine is using.

the lower down is the disc pushed. The position of the disc is communicated by the wire to the pen above, which is in contact with the revolving drum, on which is a piece of suitably ruled diagram paper. The drum is rotated by clockwork, and so a complete record is made of the quantity of steam passing at every moment throughout the day.

Lower down the drum you may notice there is a second pen at work. That is connected to a pressure gauge, so that a diagram of pressures is made at the same time and on the same paper.

The use of this apparatus enables the engineer in charge to see at any time how much steam his engines are taking. If he should notice a sudden increase at any time he can investigate it and find out the cause, thereby perhaps finding that something is not quite right, and that something is being wasted. So he can check waste, and possibly effect considerable economies.

CHAPTER XIII

MACHINES FOR TESTING STEEL

EVEN steel, the strongest of all metals, is liable to have its weak points. Generally, these are due to something wrong with the mixture, either too much or too little of one or other of the various ingredients which go to make up the "alloy," which we know by the name of steel. Fortunately, the chemical action which goes on when the steel is made ensures that these components shall always be equally distributed throughout the whole mass of metal in the furnace, and so one or two test pieces can be relied upon to give us a true statement as to the quality of the whole.

When, therefore, an engineer designs an important structure, like a bridge or a boiler, or some vital part like the tyre of a railway wheel, he specifies that test pieces shall be taken from each "blow," a term meaning that quantity of metal which is made into steel in one furnace at one time. Then these test pieces are tested by some suitable means to see if they exhibit those properties which the steel ought to possess to be suitable for the purpose for which it is intended.

The most usual of these is a test for tensile strength. The test piece is clutched between two mechanical hands and pulled until it breaks. The machine is provided with an appliance, either of the nature of a steel-

yard or of a spring balance, which measures the amount of pull which ultimately caused the rupture of the piece. In this case the stress is applied gradually, generally by means of a screw, so that the action of the testing machine is very different from that of some machines, in which steel forms a part in which it is subjected to sudden shocks. The power of steel to resist shocks can be calculated from the ordinary tensile test, but it is better to make actual tests, in which the stress is not gradual, but sudden, and it is one of the machines for this purpose with which this chapter is mainly concerned. It is a very interesting machine, for it embodies some remarkable examples of the science of exact measurement.

Of course, no measurements are exact. No one can take an absolutely exact measurement, except unknowingly and by accident. This is recognized now by the custom, in matters of fine engineering, of giving to each important measurement a "limit of error." This is in thousandths or ten-thousandths of an inch, and it means that if a hole is ordered to be an inch in diameter, it must not vary from that size more than the limit named. The astronomer, with instruments made with the best workmanship and regardless of cost, is so doubtful of his measurements, that he always measures a thing a number of times (if possible), adds them all together, and divides the sum by the number of them, thereby getting an average so as to eliminate partially those errors which he knows must be there.

But I have strayed somewhat from the subject in hand. My point was that this machine calls for very accurate measurements, measurements of time, strange to say, for the relation between time and the strength

of a piece of steel is not at once apparent. It arises in this way. A sudden blow or a sudden pull can only be applied by some moving body, and the force of the blow or pull is in proportion, not only to the weight of the body, but to the speed at which it is moving when it delivers the blow or exerts the pull. It is easy to measure the weight and the distance which it travels, but the difficulty arises when we come to measure the time which it takes to pass from one point to another, and without that information we are quite unable to determine that essential fact, its speed.

The piece to be tested is first turned in a lathe to a certain thickness; what that thickness is does not matter, so

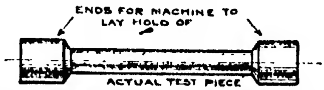
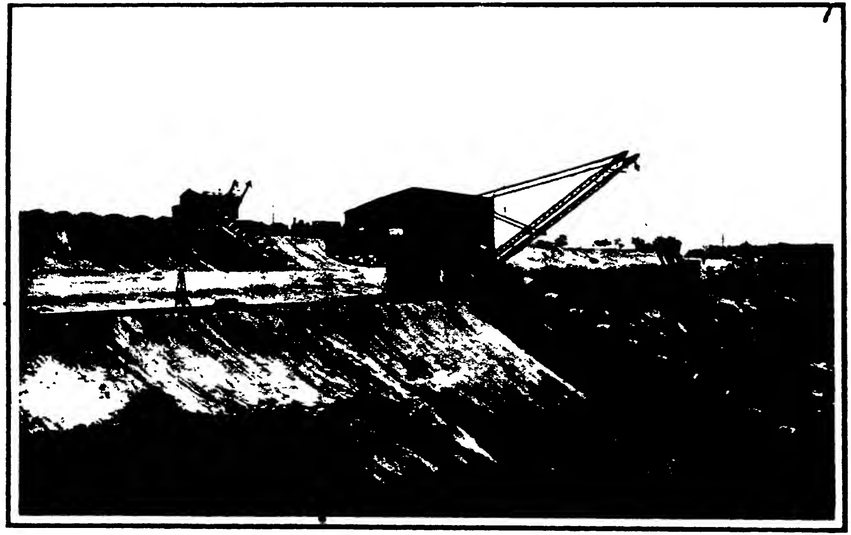


Fig. 44. How a piece of steel is shaped for testing.

long as it is not too large for the weight to break or too small to furnish an adequate test. The shape of the test piece, ready for testing, is generally something like Fig. 44; the thinner central part being the real test piece, the larger parts on the ends being simply for the machine to lay hold of, and being so much larger than the central part, they are scarcely affected by a stress which is enough to break the smaller part, so that they hardly enter into the testing process at all, except for the purpose mentioned.

Fig. 45 shows the arrangement of the apparatus. It is set up in a high building with holes in the floor, so that there shall be room to give the weight a clear fall of 40 or 50 feet. At the top there is a pulley for hauling the weight up, and at the bottom there is an anvil. This consists of two blocks of cast iron, faced with hard steel,



By permission of] *The Lubecker Machine and Manufacturing Co.*

EXCAVATING BY MACHINERY

These mechanical Excavators are scooping up earth and depositing it in railway trucks. Each machine consists essentially of an endless chain of buckets kept in motion by an engine.

supported upon steel uprights at a height of 15 feet or so above the concrete foundations. There is a space left

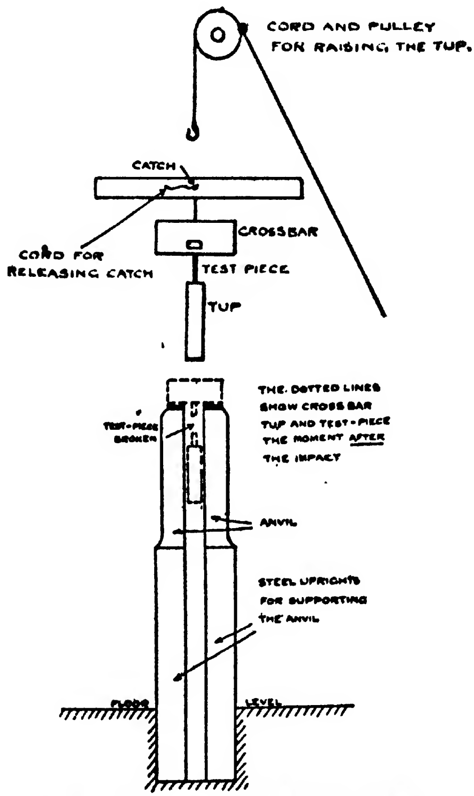


Fig. 45. The arrangement of the testing machine.

between the two blocks for a purpose which we shall see in a moment.

The test piece is suspended by one end to a strong iron crossbar, while from its lower end is suspended a weight,

known by the technical name of tup. The crossbar is attached by a catch to another crossbar near the top.

The operation of testing is this. The catch is released, and the tup, test piece, and crossbar fall together for a distance of about 30 feet. Then the crossbar is brought up short by falling with its ends upon the two blocks of the anvil (as shown in dotted lines). They are so heavy that the blow has little or no effect upon them, and so the crossbar is suddenly arrested. The tup, however, falls between the blocks, and so its progress is arrested only by the test piece, by which it is fastened to the crossbar. The weight of the tup and the height of the fall are so adjusted, in relation to the size of the test piece, that the latter is not able entirely to stop the movement of the falling tup, and so it is torn in two by the sudden pull.

That is how the test piece is broken. Now we will see the means by which the force which broke it can be measured, for that is what the machine is made to find out, and unless it can do it it is useless. It is easy to find out what force the tup was capable of exerting when the test piece was broken, for its weight is known and the height which it fell can be measured, and there is a simple rule which enables us to tell how fast a body will be travelling after it has fallen a certain distance. That rate and the weight of the tup give the energy of the tup at that moment. The difficulty lies here. We do not know how much of this energy the tup needed to expend in order to break the test piece. Suppose the test piece had been merely a piece of thread, and the weight a considerable one, then only a very minute portion of the energy would have been used in breaking it. On the other hand, it is easy to think of a case in which the test

piece would be so strong that the falling tup would be only just able to rupture it, and then nearly all its energy would be used up in doing so.

We could, of course, keep on trying experiments with a number of similar test pieces, varying the weight and height of fall, until we arrived at the point when the piece would be thus only just broken, but that would be a tedious and unscientific way of doing it, for there is a better one at hand. If we think of it for a moment, we shall see that even though the test piece be broken the pull which it exerts against the falling tup, *while it is being broken*, must slow down the speed at which the tup goes on falling. We may really think of what happens, by imagining the tup to stop for a moment, expend the energy necessary to break the test piece, and then, having broken it, resume its falling with the energy which it had left.

If, then, we can measure the remaining energy in the tup, after the breakage has taken place, and deduct it from what it possessed at the moment of breakage, we shall know how much energy it used up in breaking the test piece.

How, then, can we measure this surplus energy? As might be almost expected, electricity helps us to do it quite easily. Just as the tup passes on, after breaking the test piece, it encounters a piece of thread stretched across its path. This is tied to a little electric switch, which is very easily opened, and which immediately closes again. Current is flowing through this switch, and so the act of breaking the thread pulls the switch open and stops the current for a tiny fraction of a second. Ten feet lower down there is a similar thread attached to

a similar switch, so that that is operated a moment later. In other words, the interval between the opening of the first of those switches and the opening of the second gives us the speed at which the tup travels 10 feet immediately after the breakage. And, knowing that speed, we can easily calculate what energy it had left after the breakage.

And that brings us to the recording instruments, which automatically take a note of that interval, and enable us to work out the necessary calculations at leisure. Most people have seen a form of telegraph instrument, known as a Morse inker. It consists of a drum, holding a coil

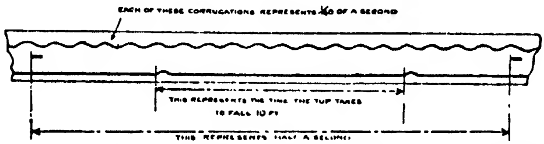


Fig. 46. Here we see the lines on the paper strip which record the speed at which the tup falls 10 feet after the impact.

of paper strip, and the strip is pulled along by clockwork between a pair of small rollers, while a pen operated by the telegraph current makes marks upon it. An apparatus of that sort is used here, the strip being made to move at the rate of about 5 inches per second. Then there are three pens at work upon the strip. Were they to remain down, touching it, they would draw three parallel lines upon it as it passed under them. One of them does actually draw a single straight, continuous line, except when one of the little switches, referred to just now, is for a moment opened. Then the pen is deflected to one side, and there is drawn a little curve in the line. The falling tup, therefore, causes a curve to be drawn each time it

breaks a thread, and the distance between the two curves on the strip forms a record of the time which elapsed between the two threads being broken.

If this interval did not need to be ascertained very accurately, it would be enough to know the speed at which the machine was paying out the strip, but that is not accurate enough. Therefore the second pen is made, by suitable clockwork, to vibrate from side to side, at the rate of forty times per second, so that alongside the first line there is drawn another one, made up of curves, each curve representing a fortieth of a second, and the number of these curves which occur between the curves in the other line tell the number of fortieths of a second which elapsed. But even that is not enough. The third pen is normally off the paper, but at intervals of half a second, under the control of a very accurate clock, it comes down upon the paper and draws a short line. The spaces between these lines then represent intervals of half a second, and form a check upon the fortieth-of-a-second curves in the other line, so that both together form a very accurate means of ascertaining the time interval which the curves in the first line represent; indeed, the interval can be determined to within ·005 of a second.[1]

Since we are here only discussing the principles on which the machine works, we need not trouble about the precise mathematical means by which the result is worked out. It will be sufficient to explain, that the calculations have been boiled down into a fairly simple formula, which anyone with a knowledge of simple arithmetic could work.

[1] This machine is installed at Messrs. Kirkaldy's Testing Laboratory, London.

CHAPTER XIV

THE GREATEST INVENTION OF ALL

Of all the inventions that the world has ever seen, none has ever had so widespread an effect as that of the steam engine. It is, indeed, in my opinion, the paramount invention of all time, for even though the internal-combustion engine should ultimately displace it, the change from the one to the other will only mean a slight increase in economy, while the change wrought by the invention of the steam engine revolutionized all manufactures and all modes of travel, and brought such a change over the surface of the globe as can never be repeated.

We have already considered the steam engine from the point of view of the theoretical power which it ought to obtain out of the coal which it uses. We have also examined some modern examples of the steam boiler, which must really be reckoned as a part of the steam engine. Now we come to the engine itself.

The first instance, as far as we know, of anything being driven by steam was a small turbine, invented by the philosopher Hero of Alexandria, just before the Christian era. It was only a toy, however, and was put to no useful purpose. The idea, in fact, seems to have slept until the middle of the seventeenth century, when several writers took up the subject of using steam pressure

as a motive power. Several attempts were made to develop the idea, but at first with little success. As I have already mentioned, incidentally, the first successful engine did not use the *pressure* of the steam, but only employed steam as a means of creating a vacuum, and so allowing the pressure of the atmosphere to do work. In this connection it is interesting to note the idea of the ingenious Dutchman, Huygens, who proposed to create the necessary vacuum by exploding gunpowder in the cylinder to expel the air.

About the commencement of the eighteenth century the matter became urgent; for there were mines in Cornwall and the North of England which were in sore trouble with drainage difficulties. Some better means than those then existing had to be found to pump the water out, or else valuable mines would have had to close. The pump was known and used, being, indeed, a very old invention, but there was lacking an adequate power to work it. These circumstances resulted in the production of the famous atmospheric engine of Newcomen. For over half a century these old engines were looked upon as the "last word" in power production. Then followed the improvements of Watt, first of all in the direction of improving the pumping engine (for up till then it had been used for nothing else), and later to the adaptation of the same machine for turning things round and so driving ordinary machinery. The real basis of the engine of to-day is the "Cornish" pumping engine, which Watt brought to a remarkable state of perfection. And no better introduction to the engine of to-day is possible.

The "Cornish" engine consists, for one may use the present tense, since the type is still used in some places for

draining mines and at waterworks,[1] of one large cylinder. One historic example had a cylinder 12 feet in diameter, but the commoner sizes are from 3 or 4 feet up to 9 feet. This is placed vertically under one end of a huge rocking lever, or beam, pivoted upon the top of a strong wall; while to the other end of the beam is attached the rod which communicates motion to the pump, known as the pump rod.

Steam is first admitted to the top end of the cylinder, so as to push the piston downwards. The piston, being connected by rods to the end of the beam above it, pulls that end down and, of course, raises the other end, thereby lifting up the pump rod. Then a valve, the "equilibrium" valve, opens and puts the two ends of the cylinder into communication, so that the steam is free to pass through a pipe from the top side of the piston to the under side. The opening of the equilibrium valve, therefore, causes the pressure of steam to become the same on both sides of the piston (hence its name), and when that takes place, the action of a weight attached to the pump rod pulls the outer end of the beam down, and raises the piston to the top once more; the steam passing from the upper side of the piston to the under side through the equilibrium pipe. So far, we have only seen what we might call a preliminary stroke of the piston. Now we can see the real stroke, which it goes on repeating for many hours at a stretch.

The piston is at the top. Underneath it, the cylinder is full of steam. The equilibrium valve closes, and two others open. One of these lets in fresh steam at the top,

[1] A good deal of the water supply of London is still handled by "Cornish" engines.

while the other lets out the old steam to a vessel near by, which is cooled by a jet of cold water. Now steam, it is important to remember, is a gas, and one of the distinguishing features of a gas is that it always entirely

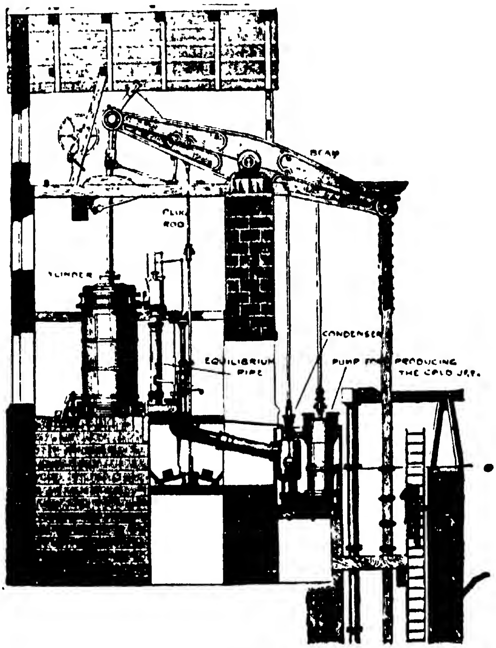


Fig. 47. "Cornish" single-acting beam pumping engine pumping water from a mine.

fills any vessel in which it may be placed, provided, of course, there is nothing else there already. The vessel, to which we will give the proper technical name of condenser, is already partially empty, for there is an air pump on the engine which pumps the air out of it. Therefore, as soon as the "eduction" valve, as it is called,

opens, the steam begins to rush into the condenser, comes into contact with the cold jet, and is immediately condensed into water. As soon as the first steam to enter condenses, which it must be understood takes place practically instantaneously, other steam rushes in to take its place, and so there is set up a rush of the old steam from the cylinder to the condenser, resulting in a rapid condensation of the whole, and producing a fairly good vacuum in the cylinder under the piston.

The other valve, the induction valve, lets steam into the top of the cylinder as before, and, since there is a vacuum below, it is able to exert its utmost power upon the piston, not having even the pressure of the atmosphere to resist it. Since, as we know, the pressure of the air is about 15 lbs. per square inch, it follows that this use of the condenser, in place of allowing the steam simply to pass into the atmosphere, is equivalent to adding nearly 15 lbs. to the pressure of the steam.

And now there is a most important thing to notice. Instead of remaining open until the piston has reached the bottom of the cylinder, the induction valve closes when it has gone only a little way. The steam pushes the piston the rest of the way by virtue of the "spring" which is in it.

A pound of steam, by which is meant a pound weight of water in the form of steam, at atmospheric pressure takes up 26 cubic feet. At 100 lbs. pressure it occupies only about 4 cubic feet, which, by the time the pressure has reached 200 lbs., has shrunk to about 2. Thus steam under pressure is like a coiled up spring, and were it admitted to the cylinder throughout the whole of the stroke, it would be still "coiled up" at the end, and its

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AN AUTOMATIC RAILWAY

The truck seen in the foreground is loaded with coal at the top of the incline. It runs down of its own weight, pulling up a balance-weight as it goes. At a predetermined point a catch releases the doors and the coal falls out. The balance-weight then pulls the empty truck back again. Thus its working is quite automatic.

spring" would only come into operation after it had been liberated from the cylinder. All that pent-up force would therefore be wasted. By cutting off the supply when only a part of the stroke has been accomplished, much of it is captured and used. For suppose it comes from the boiler at 200 lbs. pressure, and is cut off at one quarter of the stroke. Then the cylinder will be one-quarter-full of steam at 200 lbs. As the piston goes on it will give more room for the steam, which will expand, pushing the piston as it does so (but with a continually decreasing force) until it reaches the bottom. Then the cylinder will be entirely filled with steam, for the original quarter cylinder-full will have increased fourfold in volume. Now a certain quantity of steam at 200 lbs. only occupies about one-fourth of what it does at 30 lbs. Consequently, when the piston reaches the end of its stroke, the steam will still be pressing upon it with a force of 30 lbs. per square inch. The pressure will have gradually fallen from 200 lbs. to 30 lbs., but still there will be 30 lbs. left at the finish.

A difficulty arises here. Even at 30 lbs. there is a lot of work still left in the steam; indeed, the ideal thing would be to allow the steam to expand until it had lost every ounce of pressure, for until it has done that there is still work to be got out of it. But unfortunately, as we saw in the last chapter, as the pressure decreases the temperature decreases too, so if we expand the steam too much in one cylinder we cool the cylinder considerably, and then, when the next lot of steam from the boiler enters, it meets with such a chilly reception from the walls of the cylinder that it forthwith partially condenses, and much power is lost. Therefore there is a limit to the

amount of expansion which can be permitted. How this difficulty is overcome we shall see in a moment.

When the piston reaches the bottom the eduction valve closes, the equilibrium valve opens, and the piston goes up again.

We need not follow the details of the "Cornish" engine any farther, for we are mainly concerned with the more recent developments, and it has already served its purpose of illustrating the main points which have to be taken into account in any steam engine. We have seen how the steam pushes the piston, first by the pressure from the boiler due to the other steam behind it pushing it along, as a man in a crowd is sometimes pushed along by the people behind him. Then, when it is safely in the cylinder and relieved from that "pushing from behind," by the cutting off of the supply, we see how it can do work in the cylinder by the energy which is actually stored up in itself. We have noticed, too, how this stored energy can only be partially used in *one* cylinder, and we have seen the function of the condenser. With that foundation of knowledge to work upon, we can proceed to consider the more modern inventions in the realm of the steam motor.

In the "Cornish" engine the steam acts only one way. The up-stroke of the piston is idle. In the engines for producing a rotating motion Watt used both strokes. The steam entered at one end and pushed the piston one way; then it entered at the other and pushed it back, and so it went on continually. Such engines are termed double-acting, to distinguish them from those which, like the "Cornish" engine, are "single-acting." Most modern steam engines are double-acting; indeed, there is only one type

of steam engine at all largely in use now which is "single-acting." That introduces a difficulty in admitting and releasing the steam from the cylinder, which does not occur in the "Cornish" engine. In it the valves are possessed of long handles, while attached to the beam there hangs down a long vertical rod called the plug rod, from which certain pegs project. As the beam moves up and down the plug rod of necessity goes up and down too, and the pegs knock against the long handles of the valves as they pass, and so open and close them at the proper times.

Almost the first kind of valve used with the double-acting cylinders was the slide valve, so called because it works by sliding to and fro upon the valve face. This latter is a flat surface formed on the side of the cylinder, in the centre of which are three holes. Each of these holes is the end of a passage formed in the thickness of the cylinder wall. For the sake of distinction we will call them one, two, and three. If steam be admitted to number one it will pass through the passage and into the cylinder at one end. If it be admitted to hole number three it will enter the cylinder at the other end. If it be admitted to the middle one (number two) it will pass out of the cylinder altogether, either to the open air or to the condenser if one is being used. The passages are known technically as ports, the outer ones being the "steam ports" and the middle one the "exhaust port."

The slide valve itself is like a lidless box which slides to and fro upon the valve face, the two surfaces which meet being carefully scraped perfectly flat and smooth so that steam cannot get between them.

A cover is placed over the valve face so as to form a

chamber called the steam chest, inside which the valve can move about. There is a hole at one end fitted with a stuffing-box, through which passes the valve rod, whose function it is to move the valve backwards and forwards. The steam chest is in communication with the boiler, so that it is always filled with steam at boiler pressure, and it is clear that if either of the ports be uncovered steam will pass through it into the cylinder and push the piston. On the other hand, if there be steam in the cylinder already, the other side of the piston, then it will en-

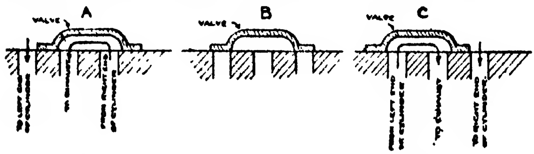

Fig. 48. Fig. 49. Fig. 50.

Three positions of the slide valve.
A. Steam entering left-hand end of cylinder.
B. All ports covered. (The "dead point.")
C. Steam entering right-hand end of cylinder.

deavour to find a way out through the other steam port, and the valve must provide a way for its escape.

A glance at the three diagrams, Figs. 48, 49, and 50, will now make everything quite clear. In the first the steam in the steam chest is finding a way through the left-hand steam port into the cylinder, and is pushing the piston to the right. Meanwhile, the steam which was left in the cylinder after the previous stroke is being pushed out through the right-hand steam port into the inside of the slide valve. Now the motion of the valve is so regulated and its size is so adjusted that the exhaust port is always open to the inside of the valve, and so the old steam, or "exhaust steam," passes through the interior of the valve to the exhaust port and out.

As the piston proceeds to the right it turns the crank of the engine, and thereby turns the eccentric which moves the valve. We need not trouble at the moment about the construction of the eccentric. It will be enough to know that the effect which it produces is to push the valve to and fro just as it would be pushed if it were connected to a small crank. Therefore, since all these parts work together, it follows that as the piston travels from left to right the valve will move from right to left, until it reaches the position shown in Fig. 49. Then for a moment both steam ports will be covered, and the engine will be on what is termed the "dead-centre." The steam will be entirely cut off from the cylinder, and will be exerting no effort at all, so that unless some other outside force keeps the piston moving the engine will stop. If it has a fly-wheel the momentum of the fly-wheel will carry it over this dead-centre until the right-hand port becomes open to the steam, which will then pass to the right-hand end of the cylinder, pushing the piston back from right to left, the steam which we saw entering in the first diagram being now the "exhaust steam," and finding a way of escape back through the same port which it entered by, and then through the interior of the slide valve to the freedom of the open air, or to annihilation in the condenser. This series can, of course, be gone through over and over again, and so the engine, if left to itself and kept supplied with steam, will go on indefinitely.

Now the steam, as we have just seen, passes out of the cylinder through the same port by which it entered, and, as we also know, it is, owing to the expansion which it has undergone, considerably cooler when it comes out than when it goes in. Consequently, as I have already hinted,

the exhaust steam cools the surfaces of the ports, and every time " live " steam enters it is partially condensed by coming into contact with the walls of the ports, which have just been cooled by the exhaust steam passing out. And that means loss of pressure and consequent loss of money to the man whose work the engine is doing. Indeed, we see there one of the places where the leakage takes place which accounts for the poor efficiency of the steam engine.

Further, the ports have to be of considerable size. They are bound to be, taking the two together, nearly as long as the cylinder, and they have to be of considerable capacity, too, for if they are too small there is friction between them and the steam rushing through them, and that means waste of power, just as much as friction in the bearings of a bicycle causes the rider to have to exert himself unduly. Therefore the steam ports hold a lot of steam. And the result is that quite a lot of it never gets into the cylinder at all. Many years ago I attempted to visit Barnum and Bailey's show when it was in London. I got as far as the crowd at the entrance, and waited there some time, only to be told eventually that there would be no more admitted that night. Now at each stroke there is a quantity of steam equal to the cubic capacity of the steam port, which has a very similar experience. It gets past the valve into the port, but since other steam has already filled the cylinder it gets no farther. When the stroke is completed it all has to come out again, and that steam in the port itself passes away to the exhaust without ever having been into the cylinder itself at all. This space which holds steam without giving it a chance to do any work is known as " clearance," and in some engines it will

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AN INVITING PROSPECT ON A HOT DAY

At many large power stations there is a difficulty in procuring a supply of cool water to cool the condensers and so condense the steam. One of the most effective ways of overcoming this is to spray the heated water into the air thereby cooling it so that it can be used over and over again

amount to as much as 10 per cent of the capacity of the cylinder.

Another weak point about the slide valve is that it opens and closes the ports gradually. Now, whenever we let steam pass through a small opening it has to *force* its way through, and so a part of the energy which ought to be available for driving the engine is wasted in that useless way. The ideal is for the valve to open suddenly and give the steam the freest possible passage for so long as we want it to flow, and then to close again just as quickly. In short, so long as the valve is open, but not wide open, it is wasting the steam's energy.

These three things, the condensation caused by the steam going in and coming out through the same ports, the loss due to the "clearance," and the waste through the slow closing and opening of the valve, are unavoidable in small and simple engines, for the cure would be more costly than the disease; but in large engines they are dealt with, and great economies effected.

There are, perhaps, no more economically driven factories in the world than the cotton mills of Lancashire, and they generally derive their power from a single Corliss steam engine of large size, frequently over 1000 horse-power. These engines are called Corliss because they are fitted with valves of a type invented by an American amateur engineer of that name in the year 1848, the purpose of which is to minimize the losses we have just been referring to.

The two diagrams, Figs. 51 and 52, show a comparison of the two valves. One represents a cylinder fitted with a slide valve, and the other one with Corliss valves.

The Corliss valve itself is very simple. It is little more

than a tap such as is used on an ordinary gas-fitting much magnified. There is a hole across which the steam passes. In this hole there fits a round plug, with a passage through it. When in one position this passage forms part of the channel for the steam; but if it be turned something less than a quarter of a circle the passage in the plug is then across at right angles to the passage, for the steam and the solid part of the plug forms a barrier past which the steam cannot travel. Then, instead of one valve, as in the case

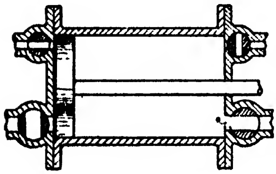


Fig. 51.
Section of cylinder fitted with Corliss valves.
(Notice how small is the waste space.)

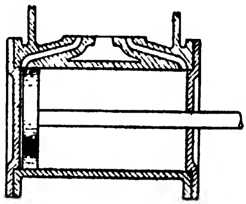


Fig. 52.
Section of Cylinder with ports for slide valve.
(See how much more waste space there is here than with the Corliss valve.)

of the slide valve, there are four to each cylinder—two inlet and two outlet. Each one is placed as close as possible to the cylinder, so that the " clearance " is reduced to a minimum, and as the steam comes in at one valve but goes out at another, that chilling action which I described just now is largely prevented.

Finally, there is an apparatus for opening and closing the valves quite different from that used with the slide valve. It is often worked by an eccentric, it is true, but the eccentric does not directly move the valve. It works through a mechanism of some sort, in which usually there are springs and catches used. There are a variety of forms

of these mechanisms, but you can easily see the idea from a general description. Imagine that the valve is fully open and the steam entering the cylinder. The eccentric pushes a rod, but it does not move the valve, for it is held in position by a catch. Instead, it compresses or pulls out a spring. When it has travelled a certain distance, however, the motion of the rod trips the catch and sets the valve free. Then, under the influence of the spring, it suddenly flies to, so that the closing, instead of being gradual, as the movement of the eccentric rod is, is quite sudden. Then, as the rod returns, the same thing is repeated, and at the proper time the valve flies open again.

I have described this at some length since it gives a good idea of the problems which confront the makers of steam engines and other machines as well, problems which are often quite unknown to those who are not actually engaged in grappling with them. One is inclined to think that a steam engine is a steam engine, and that the precise details are more or less unimportant, depending mainly on the " taste and fancy," to use a well-known phrase, of the designer. Yet the shape and form of the valves, as I have shown, make a great difference to the coal bill, a matter of no small importance when the owner of the engine comes to make up his balance sheet at the end of the year.

I mentioned just now the difficulties which were in the way of using the full expansive force of the steam in one cylinder. This was recognized quite early in the history of the steam engine, for as long ago as 1781 Jonathan Hornblower had the idea of using two cylinders, and letting the steam, after it had done work in one, pass into the other and do some more work there. At that time, however,

and for long afterwards, the pressure of the steam used was too low to make this worth doing. With improvements, however, in the construction of boilers, higher pressures became possible, and then the idea became practicable. Why the pressure makes so much difference is this. Steam at low pressure has only a little " spring " in it, and so what little there is can be very largely utilized in one cylinder. If steam at 30 lbs. pressure, for example, be expanded to three times its volume it will be just about at the pressure of the atmosphere. Therefore three times is the limit of expansion in such a case—in practice it

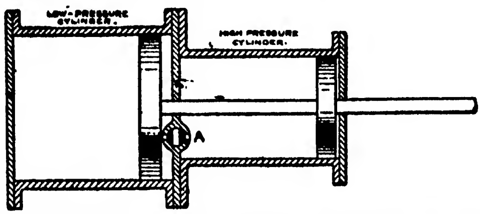
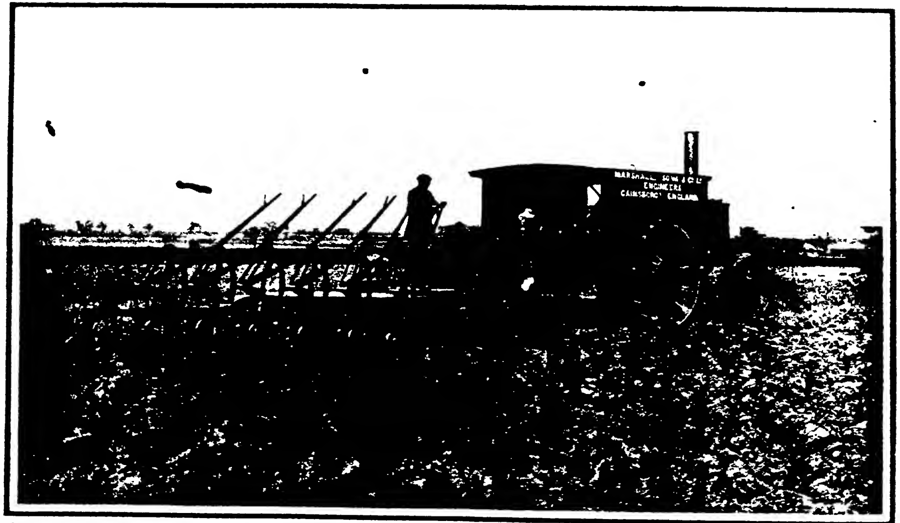


Fig. 53. Diagram explaining the advantage of using steam twice over.

would be less than three. On the other hand, if the steam be at a pressure of 250 lbs., it can be expanded thirteen or fourteen times.

At first sight it is hard to see how this use of steam in several cylinders can be any advantage. The principle of the thing can, however, be made quite clear by a concrete example. In Fig. 53 we have two cylinders, each with a piston, the two pistons being connected by means of a rod. Such an arrangement is called " tandem," from its resemblance to the arrangement of two horses in a vehicle known by the same name. It is an arrangement often used in steam engines.

You will observe that the low-pressure cylinder is much



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HOW INVENTION HELPS AGRICULTURE

This photograph shows a large plough turning up six furrows at once, operated by an Internal-combustion Traction Engine.

larger in diameter than the other. Let us suppose that its piston has an area of 200 square inches, while the smaller one is only 100. Then we will assume that the left-hand end of the high-pressure cylinder is full of steam which has just done its work there, and having been cut off early and expanded, say four or five times, has fallen to the moderate pressure of 40 lbs. to the square inch. If the valve A be opened the steam will pass from the smaller cylinder to the larger, and then there will be a force of about 40 lbs. on every square inch of both of them. The steam will, of course, be pushing the small piston to the right with a total force of 100 times 40 lbs., but it will be pushing the larger to the left with a force of 200 times 40 lbs. Since they are connected together, then, they will both move to the left with a force of 4000 lbs.

Of course, at the same moment that the valve A was opened, another valve would open too, and so new steam from the boiler would be at work on the right of the small piston; but whatever the live steam may do, it will be powerfully reinforced by the expansive efforts of the old steam left in after the previous stroke acting against the larger piston in the low-pressure cylinder.

For you must observe that the whole thing depends upon the second piston being larger than the first. If they were the same size the old steam would press with equal force on both, and in opposite directions, so that the advantage would be nil.

Sometimes more than two cylinders are used in this way, but there are never more than four. The principle is just the same, however many there may be; the steam keeps passing from one into a larger one, until nearly all its expansive force is utilized. As it expands, the same

fall in temperature takes place which would happen in a single cylinder; but when there are several the drop is divided up over them all, so that the difference between the heat of the incoming and the outgoing steam is in each of them reduced to the lowest possible limit.

When there are two cylinders through which the steam passes in succession the engine is called compound. When three it is termed triple-expansion, and when there are four it is quadruple-expansion.

Like every other good thing, however, this has its drawbacks. That is to say, there are considerations which prevent us from taking full advantage of it. For one thing, when the steam has been expanded to any great extent there is such a lot of it that it is difficult to make the ports large enough to carry it from one cylinder to another without much force being lost in friction against the walls of the ports. A greater difficulty still is to make large enough valves to control it. There is, of course, little or no limit to the size of valve which can be constructed; but these have not only to be large, they must be such that they can be opened and closed very quickly. That is the difficulty, the necessity for rapid operation. I mention this specially, for, as we shall see presently, it gives us the key to one of the great advantages of the steam turbine.

Another objection to the slide valve, besides what I have already mentioned, is that it needs so much power to move it. The force of the steam is all the time pressing it down upon the valve face, and this results in so much friction that in some cases as much as 10 per cent of the power of the steam engine is taken up in working its own slide valve. In many modern engines, therefore, a species

of valve, known as "drop valves," is used. These are formed of two small pistons placed upon the same rod like those described under the name of "equilibrium valves" in the second chapter. There are often separate drop valves for each end of the cylinder, and they are opened and closed by a spring catch arrangement such as I described in connection with the Corliss valves. In their case there is no tendency for the steam to press them down upon the valve face, and consequently little force is required to work them.

In this and the two preceding chapters I have endeavoured to let my readers into the secrets underlying the use of heat for generating power, more particularly by means of the steam engine, and to show the gradual growth of the modern steam engine, in my estimation the greatest mechanical invention of all time. In a later chapter I will endeavour to round off the subject by giving a description of several typical examples of important steam engines in which the principles we have been discussing are embodied.

CHAPTER XV

THE MODERN LATHE

In no branch of engineering have inventors been more busy during recent years than in improving this valuable old machine. And on no object could inventive genius be better employed, for it is of all machines the most useful. As far as I know, its origin is quite unknown, but it probably grew up out of the potter's wheel, or some other primitive form of appliance, which sought to shape articles by giving them a rotating motion.

Even in its simplest form it is of the utmost value, for so many things can be done with it. Volumes could, and indeed have, been written describing the many objects, some severely useful and others purely ornamental, which can be made with it. Some of the most beautiful forms, such as scrolls and curves, can be cut on a lathe by means of a few simple tools.

But the great improvements which it has undergone of recent years are most of them in the direction of making it largely automatic, so that the man who is using it can do more work in a given time.

It consists essentially of a spindle, which rotates in a horizontal position in two bearings. It is driven by means of a leather band or belt, which works on to a cone pulley, the purpose of which was explained in an earlier chapter.

A good example of a simple lathe, such as is used for

general work, is shown in Fig. 54. On the left we see the headstock, as the spindle with its bearings, pulley, etc., is termed, and the spindle is seen projecting through the right-hand bearing with a small disc attached to the end of it. That disc is a "driving plate," and the "centre," a sharp-pointed piece of steel which fits into the end of the spindle itself, is clearly projecting beyond it.

On the right is the loose headstock, sometimes called

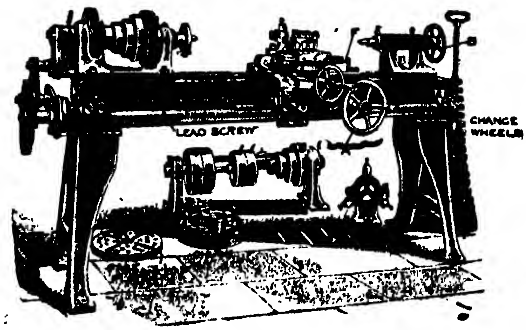


Fig. 54. A typical up-to-date lathe for general work.

the tailstock. It, also, has a hard steel centre projecting from it, which centre can be fed forward a little when needed by turning the hand-wheel D, at the extreme right of the tailstock. The latter can also be moved along the "bed," from where we see it right up to the headstock if need be, and it can be fixed at any desired point by means of a screw.

The bed is practically a strong iron beam, made very straight and true, and supported on legs, on which the other parts are mounted.

The rather complicated arrangement in the middle is

the "slide-rest," which carries the tool which actually does the cutting. It is a three-storey arrangement. The bottom storey, which is called the "carriage," can slide along the bed or be fixed as desired. To move it by hand it is only necessary to turn the hand-wheel marked A. Then, carefully fitted to it by means of a kind of dovetail joint is the cross-slide. This can be moved to and fro at right angles to the bed by the hand-wheel marked B. Finally, on the top of that is the longitudinal slide, which is moved lengthwise of the bed by the little handle F, to be seen on the right.

The tool is fixed to the longitudinal slide, being clipped down by means of two or more screws.

Now suppose we want to turn a long cylindrical object, like a bar of iron, in order to make a piece of shaft or a spindle. We bring the tailstock up till there is just room enough to get the bar in between the two "centres." Then, by means of hand-wheel D, we push the back centre up to it, until the bar is clipped between the two, but can turn round freely, supported entirely between the two sharp steel points. But that will not drive it round. In order to do that we first, before we put the bar in between the centres, clip on to it, by means of a screw, a short iron bar, called a driver, which, coming into contact with the short pin which we can see sticking out near the edge of the driving plate, is pushed round by it.

Then we put a suitable tool in the slide-rest, and slide the rest along the bed until it is at one end of the bar. We feed the tool up to its work by turning handle B until it is cutting to the required depth, and then we can either work it along by turning hand-wheel A or the handle F,

or we can leave the lathe to do it itself. If we decide on the latter, we move the handle E, thereby causing certain teeth under the carriage to engage with the thread of that long screw, the leading screw, which is so clearly shown running along the front of the bed. That is driven by means of tooth wheels from the cone pulley, and then is able to move the carriage slowly along. We can vary the speed at which the carriage will travel by varying the speed of the screw, and that can be done by changing the tooth wheels which drive it. You will notice on the right of the machine a pile of tooth wheels: they are the "change wheels," and by putting in different combinations of them the speed of the screw can be varied almost infinitely.

That is particularly useful if we want to cut a screw thread in the article we are turning. Screw threads vary according to certain standards, which generally prescribe so many threads per inch for each diameter. For example, in the well-known "Whitworth" standard, a 4-inch screw would have three threads to the inch. The change wheels would in that case be arranged so that, while the spindle turned round three times, the carriage would be pulled along by the screw exactly one inch. Then the tool, which would, of course, be a sharp-pointed one, would cut a spiral groove in the bar, in other words, a thread, having three turns in every inch.

Then suppose that, having finished our piece of shaft, we want to machine something flat, like a small fly-wheel. We shall push the tailstock right to the other end of the bed, for we shall not want it, and it will be out of the way there. Then we shall remove the centre from the end of the spindle and also the driving plate. In place of the

latter we shall screw on to the end of the spindle that round plate with holes in it which is at present lying on the floor under the lathe. That is called a faceplate, and by means of bolts through some of the holes we shall fix the wheel on to it. There will probably be four things needing to be done to the wheel. One is to turn the edge of the rim clean and true. The next will be to do the same to the sides of the rim. Then the boss (or hub) will have to be "faced," that is turned quite flat and smooth; and, finally, the hole in the centre, where it will fit on the shaft, will have to be bored out.

We can turn the edge of the rim in just the same way as we did the shaft, but for the side we shall have to turn the tool round and set it in the rest in line with the bed, whereas, of course, before it was across it. Then we shall bring up the carriage into a convenient position, and by manipulating handle C bring the tool up to its work. Then we start to turn hand-wheel B, and so move the tool across at right angles to the centre line of the machine, and so we shall cut into the wheel and take a shaving off the side of the rim. When we have done that we can do the boss in the same way, and that will bring us to the boring out of the boss. To do that we shall put in a new tool, and move the cross-slide until it is just opposite where it must begin to cut. Then, if we feed the longitudinal slide forward, it will carve its way into the metal and turn out the hole clean and true. Finally, we shall have to take the wheel off the faceplate, turn it round, and fix it again for turning the other side of the rim and boss.

But suppose that, instead of a flat article like a flywheel, it was something which could be easily held by

gripping its edges. Then we should take off the face-plate and substitute the "chuck," which is lying ready upon the floor. This is something like a faceplate, only, instead of having a number of holes, it has two, three, or four (in this instance four) jaws with which it can grip an article, like a vice. These jaws move to or from the centre in a radial direction and are worked by screws. In some one screw is made to work them all, and so, as they approach or recede from the centre all together, anything held by them must be held in the centre of the chuck. Its centre, in fact, must coincide with the centre of the lathe spindle, which is what is wanted in the majority of cases. In other chucks the jaws are independent and have to be screwed up separately: then it is sometimes a little difficult to get the work fixed exactly central, if it is so required. A machine such as I have just described is capable of doing all sorts of work; in fact, it can do almost anything, provided the object operated upon is not larger than the lathe is constructed to take. There are others, however, which are constructed for doing special kinds of work. They cannot do such a variety, but what they do they can do quicker.

The kind known as turret or capstan lathes are largely used for special work, and as they embody a number of very ingenious inventions, we will turn our attention to them. Let us take one with what is known as "wire-feed," and is employed for making large numbers of small articles, such as pins or screws, of which great quantities, all alike, are required by engine-builders and for other work.

To start with, the spindle is hollow, so that, instead of cutting up the bar out of which they are made and

putting each small piece in as it is required, the end of the bar is simply inserted through the hollow spindle, an article is made off it, the end of it is cut off, the bar is fed up until the new end is in position, a second one is made, cut off, the bar fed up again, and so on until the whole bar is used up.

There is no tailstock to a lathe of this description, but there is a more elaborate form of slide-rest. It is, in principle, like the other, but on the top of the upper slide, instead of the clip for holding the tool, there is a turret. This is either round, like a small cheese, or else hexagon, like a large nut. In each face of the hexagon, or at equal

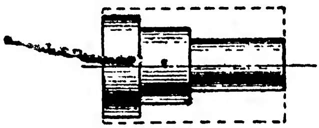


Fig. 55. The pin whose manufacture is described. The dotted line shows the original size of the iron.

intervals if it is round, there is a hole into which a tool can be fitted and held by a screw. The slide with the turret upon it can be fed up very quickly by a large hand-wheel.

Now suppose we want to make a few thousand pins like the one shown in Fig. 55, we shall need four tools, and a plain piece of iron in the turret, and we shall put one in each of five of the holes in the order in which we shall need them, starting with the plain bar. We shall make certain adjustments, the reason of which you will see in a moment, and then we shall be ready to begin. A round rod an inch in diameter is our raw material, and that we push into the hollow spindle, leaving the further end of it supported upon a standard fixed to the

floor on purpose for it. At the headstock there is a short lever, and by pulling this towards us we bring the bar forward until its end comes against the end of the plain bar in the turret. That means that we have got sticking out of the hollow spindle just the length of bar that we need for the job. Then we push the handle back, and that operates what we might call a chuck concealed in the spindle itself. No "fiddling about," you will notice, putting the bar in its place and getting a key to tighten up the chuck, or anything of that sort; just two movements of the handle and the bar is brought into the correct position and fixed.

Then the turret is run back by a quick turn of the large hand-wheel (and because it is large it is quite easy to do), and the turret automatically turns round, so that the first tool takes the place of the short bar and is ready for its work and in the correct position. Then we feed that forward, and it cuts the half-inch portion roughly to size. As soon as it has pared down the bar to nearly half an inch in diameter for a length of an inch it comes against a "stop," which we had previously adjusted, and will go no further. So we run it back again, the turret turns again and brings the second tool into position. That we bring forward and so cut the ¾-inch portion roughly. Again a stop prevents us from going too far, so we back the slide, and this time a "finishing" tool comes into play, which takes a thin finishing cut off the ½-inch part, to be followed by one which finishes the ¾-inch part.

Now there is another little appliance which has not yet been mentioned, a small slide-rest which works *across* the centre line of the lathe only. Its main function is

to cut off the work from the bar when it is finished, but it can be put to other uses as well. It has two posts, to each of which a tool can be fastened, and these stand up on either side of the work, while the slide itself runs underneath the work. Thus, if we bring the slide towards us, the tool fixed the other side comes into contact with the work; whereas, if we move it away from us, the tool nearest to us comes into action. One of these tools we arrange so that it will shape the head, while the other cuts the finished pin from the bar. We have a short lever by which we can quickly move this slide, so as soon as the last tool in the turret has done its work we push the lever from us. In less time than it takes to tell it, the proper shape has been given to the head, then the lever is moved in the opposite direction and the pin is cut off. Another quick movement of the feed handle and the bar is fed forward and gripped, ready to start making another, the turret is brought up, and the whole thing gone through again.

Anyone who has followed this description will be forced to confess that we have here a wonderful invention. The simplicity of it all—the turret with all its tools ready and waiting their turn to come into action, the stops which make everything come the right size without any measuring, the feeding in of the long bar, and the gripping of it by one to-and-fro movement of a handle—it is all so simple, so quick, and so effective that it compels our admiration.

But we can go a step further. What has been described is a semi-automatic lathe. There are full automatic lathes, in which the operations just described follow each other almost spontaneously, with very little attention

from anyone. I will not attempt to describe the mechanism of these except in general terms. When you review the actions of the workman in operating a semi-automatic lathe you will see that they consist simply of two motions. There is first the to-and-fro motion of the feeding handle, and then a turning of the hand-wheel, which works the slide on which the capstan stands. There is no need for intelligence or skill after the machine has once been adjusted; and therefore it is not difficult to see that a simple mechanism added to the semi-automatic will enable it to perform these two movements automatically.

In working brass different methods can be used from those necessary with iron or steel. For one thing, brass is so soft that it can be turned at a higher speed, and so "brass-finishers'" lathes often have no "back gear," but are driven direct by the belt, the cone pulley being fixed upon the shaft.

For some purposes a lathe is better if it be stood up on one end. Of course, I do not mean that a lathe such as I have been describing should be hoisted into that undignified position, I mean that lathes are made which rotate about a vertical axis. They are then generally called turning and boring mills, but they are actually vertical lathes. One great advantage which they have over the ordinary lathe is that the work is so much easier to fix. This seems a prosaic reason to the general reader, but it is an important one to the works manager, who has to get a given amount of work done with the minimum of labour. Just now, in imagination, you assisted me to turn and bore a wheel. Now suppose that wheel weighed only a hundredweight, not a very great

weight, do you think you or I could have fixed it in the chuck or on the face-plate single-handed? For certain we could not, but when the face-plate is like a table, and only a couple of feet or so from the ground, it is quite different. One strong man could do it then, for he would only need to lift it on, and then he could push it into its place, and there it would stop of its own weight until he fixed it. Indeed, it needs very little fixing to the face-plate, for its own weight, which makes it so awkward in the lathe, is an actual help in the boring mill. In short, it is like the difference between fixing a thing on the wall and on the floor.

In modern engineering, accuracy is the great thing. A thousandth of an inch is quite a large error, and even the best lathe is not accurate enough for some work. Moreover, some steel used in modern machinery is too hard to be cut by a tool in an ordinary lathe. Then a variety of lathe called a grinding machine is used, which can make things accurate within much finer limits than a thousandth of an inch, and which can tackle the hardest steel.

These machines are practically only lathes, in which a revolving wheel of emery takes the place of the tool. There is this further difference, however. In the lathe the tool moves along the work, cutting as it goes. In the grinding machine the wheel is more often stationary, except for its rotating motion, and the work, also revolving, moves in front of it. Both headstock and tailstock are mounted upon a sliding bed, which is able to slide along upon the bed proper. Thus the work travels along and turns at the same time, and as it does so the emery wheel grinds it.

CHAPTER XVI

SOME MODERN STEAM ENGINES

In a previous chapter we traced the gradual development of the steam engine, and noted some of the features which have helped to bring it to its present state. In this chapter I propose to give a brief description of some recent specimens, typical of the steam engine of to-day.

Pumping water was the first use to which steam engines were put, and this duty is still a very important one. There are some splendid examples of machinery, therefore, to be found in the up-to-date waterworks. Such engines are usually very large, for unless pumps of the centrifugal type are used the speed has to be very slow. A little high-speed electric-light engine may therefore be rated at as many horse-power as a large pumping engine, yet it will be but a fraction of the size. The reason for this is the heavy, inelastic nature of the substance which they have to deal with. The pumping engine has to push by main force a body of water weighing many tons along pipes perhaps miles long. To do this at a high speed would produce higher pressure in the mains than they are able to bear, and so the action of such engines is always slow and deliberate.

I saw recently one of the latest engines installed by the Water Board of London, possibly the largest of its type in existence, and a short description of it may be interesting. The engine-house is a massive rectangular building,

and the engine occupies the centre. The engine itself is a three-storey structure, for it has two stages built around it above the floor-level. Let us ascend the stairs to the highest level to commence with. There we are on a level with three massive cylinders (for it is triple expansion), which appear as if they were standing vertically upon the floor on which we are.

The largest of these is 5 feet in diameter, and they are all long enough for the piston to move 4 feet at each stroke. In front of us runs a shaft, which operates the valves, of the " drop " type already described.

Descending then to the next floor we are able to see the massive iron columns which support the cylinders above us, and, of course, the platform which we have just left. We also see here the re-heater, through which the steam passes on its way from one cylinder to the next. This consists of passages kept hot by live steam direct from the boiler, so that the partially used steam which has lost some of its heat is here able to pick up some more and go on its way rejuvenated, as it were. Here, too, we see the massive piston rods issuing from the ends of the cylinders, and going up and down with apparently irresistible force.

On descending further to the ground-level we get a view of the great shaft with the three heavy cranks formed in it, and at each end a huge fly-wheel, 15 feet in diameter. Strong steel rods convey the motion of the engine down through the floor to the pumps in the chamber below.

The cranks are set at an angle of 120 degrees, so that the turning effect of all three cylinders combined shall be as nearly as possible uniform. This seems a simple matter, but it is of considerable importance, for there is one point

in the piston's career, namely, just as it reverses its direction, when it is doing no work. If the cranks were all set the same way, or even if one were set exactly opposite to the other two, this "dead centre," as it is called, would occur at the same moment in all three cylinders. Being set at 120 degrees apart, however, the dead centres occur in succession at equal intervals, and never two together. Just as one cylinder is doing for the moment no work at all, the other two are in a position to work well, and so the turning effect is kept uniform. The same arrangement, it may be interesting to note, prevails on locomotives. There there are two cylinders, and the cranks are placed at right angles, apparently a clumsy, unbalanced arrangement. It would seem as if it would be much better to put them opposite so that they may balance each other. Yet really it is most important, for it prevents a locomotive ever stopping upon a dead centre and being unable to start itself. So long as they are at right angles, even should one be on the dead centre, the other would at that moment be in the position to exert the greatest power. So the turning effect of the two is uniform.

The huge fly-wheels, too, are specially needful in pumping engines, for, as I have already said, it is not practicable with any ordinary pumps to move the water very fast. The engine is, therefore, always working against what we might call a dead load. The rotating part of a dynamo, for example, is quite different, for it is to a certain extent "alive" by virtue of its momentum, and so helps the engine driving it to keep up a steady speed.

The slowly moving column of water, however, needs to be continually pushed along, and so, but for the fly-wheel, the expansion of the steam would be impossible.

At the commencement of the stroke, with the full boiler pressure, the piston would move rapidly; but as the steam expanded after it had been cut off, and the pressure fell in consequence, the power would diminish, the piston would slow down and probably stop before the end of the stroke. The fly-wheel alters all this. It is a reservoir of energy. It takes up energy at the first part of the stroke, when the steam has a surplus of power, and gives it back later on when it has a deficiency. Theoretically it must vary in speed to be able to do this, but if it is heavy enough, as it always is in good engines, the variation is so slight as not to be noticeable.

The speed is regulated by the usual centrifugal governor, so familiar to everyone. I spoke not long ago with a man who told me that the only part of a steam engine that he knew anything about was the governor. Such a prominent feature as it is always attracts attention. In this case, as is usual with high-class engines, when the engine tends to go too fast the governor does not throttle the steam pipe as it does in small engines, but changes the moment of cut-off, so that the live steam is cut off from the cylinder at an earlier period of the stroke. That is because, as I pointed out in an earlier chapter, it is wasteful to let steam pass through a restricted passage, for it loses some of its power in forcing its way through. Therefore the passage for the steam is kept fully open, so long as steam is passing, but is entirely closed slightly earlier. Then it is also arranged that if the speed increases beyond a certain point it throws the valve gear (the apparatus, that is, which works the valves) out of action altogether and so stops the engine. The idea of that is to provide against the bursting of the water main. Normally, per-

haps, the engine is forcing water along miles of pipe, and perhaps, too, to a considerable height (in this particular engine the height is over 200 feet), and, of course, the

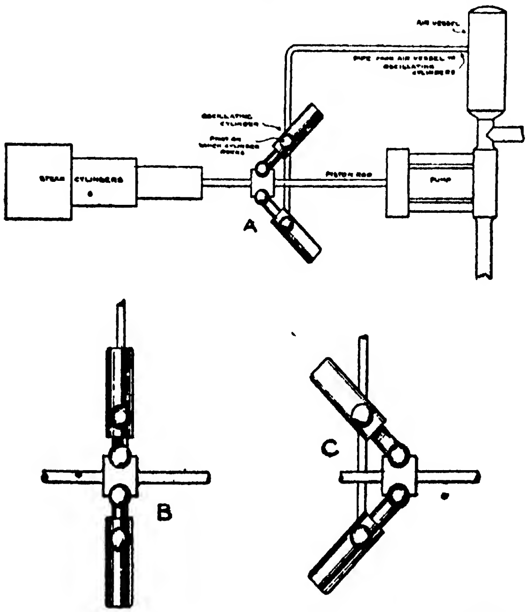


Fig. 56. The shaded parts of these drawings do not look like a flywheel, yet that is what they are in effect.
A shows the position of the oscillating cylinders when the piston rod is moving to the right and they are absorbing power.
B shows them at the middle of the stroke when they are doing nothing.
C shows them giving back the absorbed power and helping the piston rod along.

engine is constructed to work at its normal speed under these conditions. If, however, as sometimes happens, the main bursts, the engine has maybe to force the water only a few feet, and then it would commence to "race."

Under those conditions the governor, as I have just explained, stops it altogether.

There is another kind of large pumping engine which is of interest, since it contains an ingenious substitute for a fly-wheel. It is known as the Worthington pumping engine, after the famous American engineer of that name who invented it. It generally has three cylinders too, but they are placed tandem, that is, one behind another. There are no rotating parts, but the piston rod passes straight from the pistons to the pump.

At the centre of the engine there is a pair of small oscillating cylinders connected to the piston rod (as shown in Fig. 56) by a kind of knuckle joint. They do not look much like a substitute for a fly-wheel, yet that is what they are. These small cylinders are full of oil, and a pipe connects them to the water main. Consequently the pistons in them are always being pressed outwards with a force per square inch depending upon the pressure in the main. When the steam starts to push the piston along, the small cylinders are inclined towards it and so resist its movement. At that time, however, the full boiler pressure is at work, and so the steam, forcing the piston rod along, pushes inwards the pistons in the small cylinders. By the time the piston rod has made half the stroke the small cylinders are vertical, and so are neither helping nor resisting. A moment later, however, they begin to be inclined in the direction in which the steam piston is moving, so that they begin to help it along. Just at the time, then, when the steam in the large cylinders is expanding, and so losing power, the small cylinders come to its assistance and help it to complete the stroke. It is just as if there were a strong spring inside the small

cylinders, which the steam compressed when it had power to spare, and which in turn helped the steam when it needed it later on. Thus they perform the same functions which the fly-wheel does in the ordinary rotative engine.

And now just notice the cleverness of connecting the small cylinders to the water main. It is, of course, a very convenient way of giving it that elastic force which it needs in order to do its work, but it has another purpose. Suppose the main bursts. Instantly the pressure falls in the main, and in the small cylinders too. At the end of the very next stroke the piston rod lacks the assistance which ordinarily the small cylinders give it; it is unable to complete its stroke and so stops dead. As a gentleman who had had much to do with these engines remarked to me, if the main bursts the engine "stops and looks at you."

In the above description I have purposely made one inadequate statement, for it simplified the description to do so, and I knew I could correct it afterwards. The small cylinders are not connected to the main directly, but to a large iron vessel containing air which is itself connected to the main. The purpose of this air vessel is to act as a cushion. The water in the main is very heavy and very "solid." There is no "give," no elasticity in it, and so the strokes of the pump, slow though they be, are apt to impart jerks to the water. There is no "springiness" in the water itself to absorb these jerks, and so the air vessel is provided. At every stroke some water is forced into the air vessel, compressing the air somewhat in order to find room for itself. Between the strokes the compressed air pushes this water out again, and so a perfectly even, steady flow is ensured. The soft, giving nature of the air

makes up for the incompressibility of the water. It is the " springiness " of this air, too, which is communicated to the oil in the small cylinders, so that the effect of a spring contained in those cylinders, to which I referred just now, is really due to the air.

Perhaps I may be permitted to mention here a simple contrivance which is used with the old " Cornish " engines

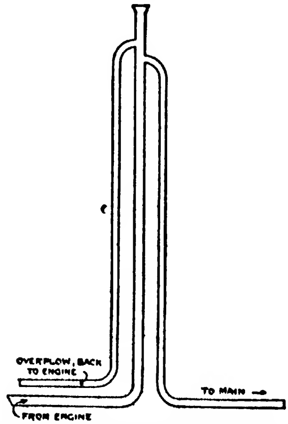


Fig. 57. The "gigantic trombone," often seen at waterworks.

to protect them against the effects of a burst main. I do so apologetically, for it is decidedly old, yet it is the subject of so many questions that I think I am justified in introducing it. It is called a standpipe, and there is an example of it well known to all the residents in South-West London just near Chelsea Bridge. It consists of a number of vertical pipes, a little higher than the highest point served by the water main. The pump forces the water up one of these, and near the top it finds its way through a short connecting pipe into the second one, which leads

it to the main. The engine, therefore, is engaged in pumping the water up to that point, and from there it flows by gravity to its destination. Should the main burst no harm will come to the engine, for it will still have to pump the water up as high as ever. The third pipe provides against the stoppage of the main or the engine pumping the water faster than the main is taking it away, for it, too, is connected by a short pipe to pipe number one, but a little higher up, so that if the water does not flow away through the second pipe it rises higher and falls back again through number three. Thus the engine is always doing the same amount of work whatever happens, and can neither be pulled up with a jerk owing to the main being stopped or allowed to run away through the main bursting. In the example which I have referred to specifically the same engine serves two mains, so that in that instance there are two "number two" pipes, but in the majority of cases there is only one. The whole apparatus very much resembles a gigantic trombone, and it is generally of such a great height that wherever there is one it is a very prominent object.

To return to the subject of engines, another example is to be seen in the illustration given herewith. It is a fine example of the type of engine which drives the large cotton mills in Lancashire, but the inscription under the illustration is sufficiently full to render further description here needless.

Another important class of steam engines is the high-speed, or quick-revolution, engines, which are used for driving dynamos, often spoken of as electric-light engines. When electricity first came into use engines of the type used for driving mills were adopted. They worked at a

slow speed, and to enable them to drive the fast-running dynamos they were connected by a belt, a large wheel on the engine working on to a small one on the dynamo. That

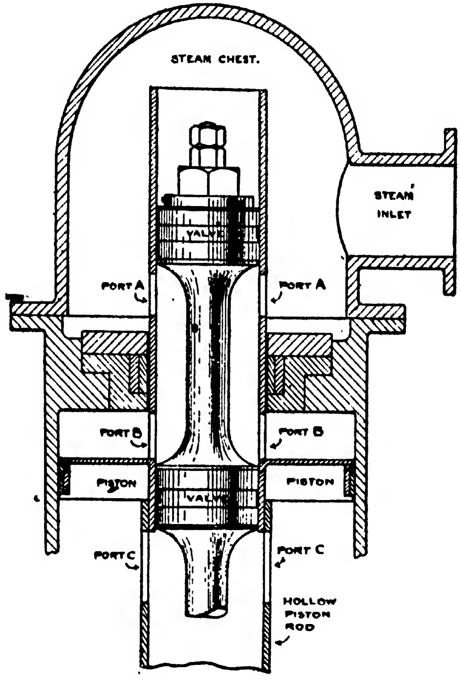
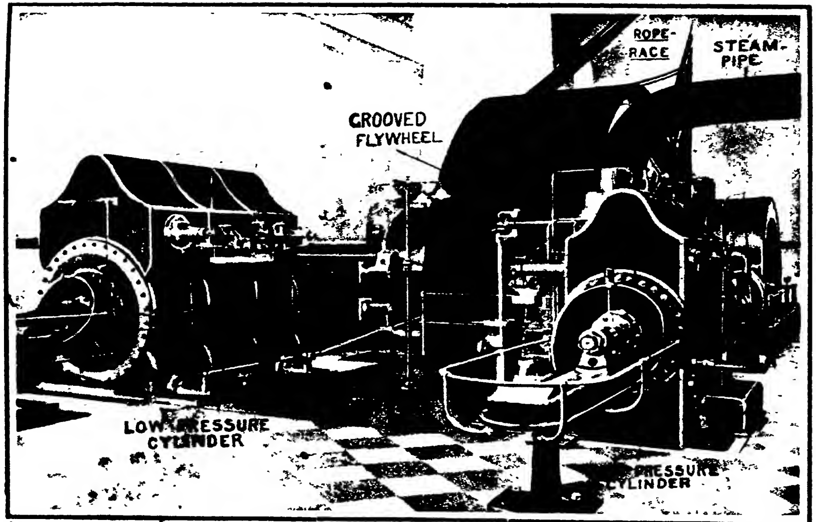


Fig. 58. A fragment of a "Willans engine," slightly simplified. Steam is here entering ports A and issuing from ports B into the cylinder *above* the piston. Observe that as the piston-rod descends ports A become closed, also that when the valves move upwards inside the rod the steam can pass from B to C instead of from A to B, and so pass from *over* the piston to *under* it.

arrangement took up a lot of floor-space, necessitating large generating stations, and also there were apt to be troubles with the belts. Therefore it soon became evident



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ONE THOUSAND FOUR HUNDRED HORSES

This fine Compound Steam Engine is a splendid example of the kind of engine employed to drive Cotton Mills. The huge Flywheel has grooves for about 40 ropes which convey the power to the various floors.

that smaller engines, of the vertical form and running at the same speed as the dynamos, would be an advantage. They could then be put in a much smaller space and could be connected directly to the dynamos; that is to say, the shaft of the engine and the shaft of the dynamo could be connected end to end. Thus both the objections mentioned were overcome.

And so the electric-light engines came into being. One of the first was a remarkable engine, invented by Mr. P. W. Willans, still known by his name and still largely used. One notable feature of this engine is that the slide-valves are inside the piston rod. I say valves because there are usually several cylinders one above another, with one piston rod common to them all. The hollow rod has ports in it, and these are covered and uncovered as it passes up and down through the floors of the cylinders. They are also covered and uncovered by the movement of the slide-valve inside, and these two together cause the steam to pass at the right moment from one cylinder to the next. The valves are like a lot of small pistons fixed upon one rod, and they are worked by an eccentric placed upon the crank. The upper cylinder is always the high-pressure. Over the top of it there is a dome-shaped steam chest, into which the piston rod projects. At the right moment ports are uncovered and the steam finds its way into the hollow piston rod. It travels a little way down and then comes out again inside the cylinder and above the piston, so that it drives it downwards. On reaching the bottom of the stroke other ports in the rod are opened and the steam passes in and down to the under side of the piston, permitting it to rise just as the piston in the "Cornish" engine can rise when the equilibrium valve

opens. Then at the next stroke the steam passes from under the high-pressure piston into the low-pressure cylinder in just the same way that it had previously entered the high-pressure cylinder from the steam chest. It then passes to the under side of that piston, and if it be a triple expansion engine thence to a third cylinder, or, if it be compound merely, to the condenser. The action of the steam is downwards only. This is, in fact, the engine which I referred to earlier as the only single-acting steam engine in extensive use now.

The reason why it is single-acting is very interesting. Its high speed makes those parts which work in contact very liable to wear. For example, the bearings in which the crank shaft turns would be very liable to become slightly oval. Then, if the crank were alternately pushed and pulled by the action of the piston, as would be the case in a double-acting engine, the shaft would knock up and down, and, again particularly because of the high speed, that knocking would soon ruin the engine.

This could obviously be kept right by continual adjustment, but that is a thing the need for which should be avoided in a good engine. Mr. Willans conceived the idea that if he made the engine single-acting so that the piston *pushed* only, and never pulled, he need not trouble about this, for the bearings might wear down very considerably, and yet there would be no knocking, for the simple reason that the shaft would always be held firmly down in the lower half of the bearing. Indeed, he practically did away with the upper half of the bearings altogether and let the shaft run in a semicircular groove. He enclosed the lower part of the engine, too, in an oil-tight case, and filled the lower part of it with oil, so that

at every revolution the crank dips down into the oil and splashes it all over the working parts. Thus he ensured good lubrication.

Another beautiful example of the high-speed engine is that known as the Belliss engine, after the name of its makers. It is more normal in construction than the Willans, inasmuch as it is double-acting and it has a slide valve on the side of the cylinder. This valve is of the "piston" type, which has been mentioned earlier. In this case the "knocking" difficulty has been overcome in the opposite way. The designers of this engine have actually made the high speed, which is the cause of the trouble, furnish the cure as well.

Oil, of course, has a certain amount of "viscosity"; that is, it does not flow freely like water, but has properties more like those we are in the habit of associating with treacle. If, therefore, a film of oil be placed between two surfaces, it does not immediately run out, nor even does it permit itself to be easily squeezed out. It remains and holds the two surfaces apart, preventing them from touching each other. Even if there be considerable pressure, tending to force the two surfaces together, it will take some time to squeeze the film of oil out and make them touch.

In the Bellis engine advantage is taken of this fact. Oil is forced into the bearings by means of a pump, so that there is always ensured a film of oil between the parts, which would otherwise be in contact. As the piston comes down it tends to squeeze out the film of oil on the under side of the shaft, but before it has had time to do that, owing to the high speed, the piston has started on the up stroke, the downward pressure is relieved, and the film

of oil has time to reform before the piston comes down again. The same thing must needs happen during the up strokes, in the upper side of the shaft; and so the shaft and bearings do not, in fact, often actually come into contact, but there is always a film of oil between them. Engines of this kind have been known to run for years, making millions of revolutions, and then, when taken apart, there is no wear at all to be found in the bearings; indeed, scarcely any evidence of their ever having touched each other.

This simple but perfectly effective way of surmounting a very important difficulty is nothing but a stroke of genius.

But I fear I have already said enough upon this great subject, the steam engine. There are other important inventions to which I must turn, so with this I must leave this fascinating subject.

CHAPTER XVII

INVENTIONS IN THE COTTON MILL

THERE are probably no inventions which have added so much to the happiness of mankind as those which are in daily use in modern cotton mills. In the old days it took one person to manage one spindle, but one man with one or two boys to help him can now look after 1000 spindles. Of course, the modern workman with his 1000 spindles needs the assistance of a steam engine, while the spinster of years ago did all the work herself; but even allowing for everything, modern methods represent an enormous saving in labour, resulting in a great cheapening of an article which is of the greatest use. Indeed, were it not for the present methods of manufacture by machinery, it would be impossible to produce as much cotton as the world needs.

Anyone taking a hasty view of the machinery in a cotton mill would probably be bewildered at the extreme complexity of it all. Almost wherever he goes he will see thousands of things all moving at once; but as a matter of fact, many thousands of them are all doing the same thing, so that to understand one is to understand all, and while the details of them are not easy to grasp, the main principles which underlie them all can be explained simply.

The raw cotton enters the mill in bales, covered with rough sackcloth, and bound together by a number of

iron hoops. In appearance the cotton is like the familiar cotton-wool, or wadding, except that it has among it grains of sand, husks which have not been taken out (for, you must remember, cotton is obtained from a seed), and other foreign substances, and the task of the mill is to convert this into fine yarn. Yarn is not like sewing cotton, the form in which cotton is most familiar to us, since the latter is made of a number of strands of yarn all twisted together. It is a common thing to see on a reel of cotton the words "6-cord sewing cotton," which means that the cotton on the reel is made by twisting six strands of yarn together; and anyone who desires to see real cotton yarn has only to unravel a small piece of sewing cotton and separate the six strands from one another.

At first sight the task of converting the soft, fibrous "cotton-wool" into a strong, fine thread would seem to be an extremely difficult one; in fact, if a piece of yarn and a piece of raw cotton be put side by side it seems hardly credible that the one is made from the other. The work is done, however, entirely by machine, and the whole operation goes on with such remarkable smoothness and method as seems to make everything quite simple.

The bales of raw cotton having been undone, the cotton is found to be tightly squeezed together, it having been compressed in order to minimize the space taken up on the ship which brought it here.

The cotton in the bale, therefore, separates into lumps, and these lumps have to be broken up and the fibres which form them shaken apart so that they can be manipulated into yarn. Yet on no account must the fibres be broken or the quality will be spoilt, so the operation must be as gentle as possible.

Inventions in the Cotton Mill

Imagine an endless band made up of laths, like a venetian blind, with a row of wires sticking upwards upon each lath. Imagine also the blind to be always going up, not vertically, but up a steep incline, and then you will have an idea of a machine which breaks up the lumps of compressed cotton. The lumps are thrown upon the laths and are carried upwards by them. Their own weight, however, makes them roll down again, and so they are kept in a state of continual motion, resulting in their being shaken up into small, soft pieces. These small pieces the wires upon the moving laths are able to hold and carry up to the top, where they are delivered to the next machine.

This has for its purpose the removal of the dirt from the cotton. A number of arms projecting from a revolving drum throw the cotton about, the particles of dirt, because of their greater weight, falling out, and dropping through a grating, while the lighter cotton is carried over. It passes out of this machine through rollers, which squeeze it into a flat sheet, something like white felt.

Here we encounter the first of the great principles which occur over and over again in a cotton mill. The great object, you must understand, in cotton manufacture is to produce a yarn which shall be perfectly even and regular in size and quality. Not thick here and thin there, or strong here and weak there, but the same from end to end. Now, of course, there are liable to be variations in the raw cotton, some of which will be a little better than others; and in some cases different kinds of cotton are deliberately mixed, in order to produce a medium quality of yarn. For instance, the cotton used

comes from various parts of the world, such as the United States, Egypt, and India, and these different countries produce different classes of cotton—the main difference between which lies in the length of the fibres. If you examine a piece of cotton-wool, you will find that it does not consist of long lengths, but of a great number of short fibres all matted together. The fibres which come from some parts are perhaps as short as three-quarters of an inch, while those which come from other parts may be over an inch long, and the longer they are the better yarn

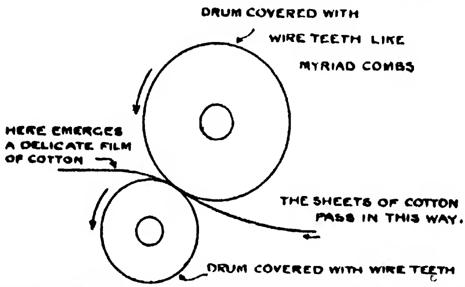


Fig. 59. This diagram illustrates the working of the wonderful "Carding machine," which puts all the millions of tiny fibres the same way.

they make; consequently the best yarn would be made from the longest fibre procurable, while the cheapest would be made from the shortest, and the intermediate qualities from other kinds of raw cotton, or from mixtures. Consequently throughout the whole process there are continual mixings going on, so as to ensure that the mixture shall be very thorough, and the final result as nearly as possible absolutely uniform. For this reason five of the flat felt-like sheets which come from the cleaning machine are put together, one on top of the other, and rolled into one. Then the single thick sheet passes to the carding machine.

This machine performs what at first sight seems almost impossible. As I remarked just now, the fibres in a piece of cotton-wool are twisted together in apparently hopeless confusion, and it would seem to be quite idle to expect any machine to straighten them all out and lay them parallel with each other. Yet that is the work of the carding machine, a work, too, which it accomplishes with perfect success.

The principle of this machine is shown in our diagram, Fig. 59. It consists of two revolving drums, or cylinders, one considerably larger than the other. The upper one is covered with fine, short wires, like bristles. The lower and smaller drum is also covered with short wire bristles, only instead of standing straight up like those on the larger one, they all lean slightly in the direction in which the drum turns.

The sheets of clean cotton are fed on to this smaller drum, and the small bristles, because of their inclination, catch the material and carry it forward. Now as it thus passes over the smaller roller the bristles of the upper roller, which are moving in the opposite direction, act like a vast number of tiny combs, and comb out the cotton in such a way that all the fibres are separated and laid in the same direction, just as brushing one's hair lays all the hairs in the same direction. The transformation is most astonishing. At one side there passes in a rough, thick sheet of rather dirty-looking cotton; from the other side there flows a beautiful film of soft, fleecy material. You might imagine it to be a fall of very soft snow, only it is flowing in a horizontal direction instead of a downward one, and though the fibres are thus separated, so as to produce this filmy, transparent effect, they are near

enough together and have sufficient hold upon each other to permit the whole sheet, several feet wide, being drawn through a sort of metal funnel. This forms it into a very soft, tender rope, about as thick as a man's finger.

This rope is so soft and frail that it needs the most

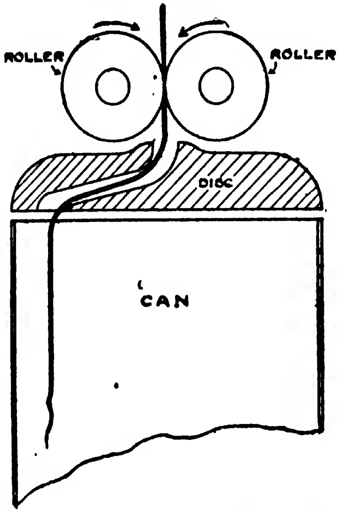


Fig. 60. Here we see the beautiful little mechanism which draws the soft "rope" of cotton from the Carding machine and coils it in the can as a sailor would coil a rope.
The two rollers draw it in; it passes through the slanting hole in the revolving disc, and as the latter turns around upon a vertical axis, it coils it in the can beneath.

careful handling, and were it to get entangled there would be nothing for it but to send it through the carding machine again. Therefore, in order that it may be carried to the next machine, it needs to be carefully coiled up in a deep cylindrical tin can. This is done by a beautifully simple but effective little piece of mechanism, which is shown in our diagram, Fig. 60.

It consists of two small rollers turning in contact with each other, while below them a steel disc revolves about a vertical axis. The soft rope of cotton is drawn in by the two rollers and passed down into a hole in the centre of the disc. That hole is the entrance to a little tunnel or passage, which passes through the thickness of the disc and has its other end not at the centre, but near the edge. As the machine works, the disc turns round and round, and the cotton, fed in by the rollers at the centre of the disc, emerges from it near the edge. The revolving motion thus causes it to be coiled round and round into the can which stands beneath. By this means quite a long length can be carried about in the can without fear of its getting entangled.

The action of passing through the two rollers just mentioned converts this rope, as I have called it, into something more resembling a tape, by which term we might describe it at this stage. Half a dozen cans of this are then taken to another machine, in order that further mixing may take place, the tape from each of these cans being led simultaneously to another pair of rollers, and there squeezed into one tape. Then very often six of these tapes are passed through another similar machine and again consolidated into one. This, also, is for the purpose of more thoroughly mixing the cotton together.

At this point we come to the second great principle which underlies the manufacture of cotton-yarn. The first, you will remember, is the mixing at every possible opportunity of different quantities of cotton, so as to produce a uniform quality. The second is a continual stretching, first of this tape, as I have just called it, until it has become a fine thread, and then the thread into a

finer one still, until it is so fine in some cases that a self-respecting spider might hardly be ashamed to own it.

How this continual stretching is performed is shown in our next diagram, Fig. 61. There you see four pairs of rollers, each pair running in contact with one another. As I have drawn the diagram, I am assuming that the cotton passes through from left to right, and in that case the pair on the extreme left will be moving fairly slowly, the next pair a little faster, the next pair a little faster still, and the fourth pair the fastest of all. The result is

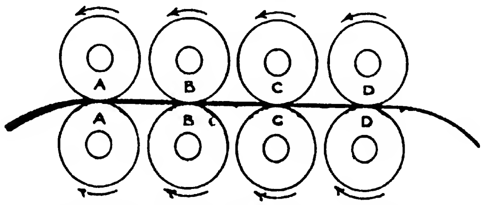


Fig. 61. This shows one of the main features of the machinery in a cotton mill. The cotton passes first through the pair of rollers A, thence between the pair B, and so on. Each successive pair turns faster than the preceding ones and so the cotton is gradually drawn out thinner. If the pair D turns six times as fast as A, then every yard of cotton which enters the series comes out as six yards.

that, as it passes through these four pairs of rollers, the cotton goes through a gradual stretching process; and if, as is generally the case, the fastest pair are moving six times as fast as the first pair, the result will be that, for every yard which goes into the apparatus, 6 yards will come out, and, of course, the 6 yards will be proportionately thinner than the 1 yard. Up to this point the fibres of cotton are all straight. They were straightened out by the combing action of the carding machine, and nothing has been done to disturb them since. When they are like this they have a certain power of holding

on to each other, so that the tape we have just been talking about is able to hold itself together, but it can do little more. In order to give it more strength it needs to be twisted, and that brings us to the third great idea in cotton-spinning. In fact, after the carding machine has been passed the whole work of the mill might be summed up as mixing ("doubling"), stretching, twisting.

Now it is easy enough to twist a short length when you can get hold of both ends and stretch it out straight, but to take a long length of tape from a can, or of thread from a bobbin, and wind it on to another bobbin, twisting it as it passes from one to the other, is by no means easy. In fact, the little apparatus which does it, which is called a "fly," constitutes a remarkably clever invention.

Perhaps I ought to explain that the machines in which this is done are spoken of collectively as "fly frames." They are long, narrow machines, and stand parallel to one another, stretching right across the whole width of the mill. At the back are rows of cans, which contain the cotton as it came from the last machine, while lower down and in front are the "flies." The cotton passes from the cans above through a series of rollers like those described just now, which have the effect of stretching it, and thence to the flies, which twist it and wind it upon bobbins. The action of this wonderful little contrivance is shown in our next diagram, Fig. 62. The bobbin is fixed on the top of a hollow, vertical spindle. Down the centre of them both there is another spindle, and from the top of this, on each side, there hangs down a little arm, forming, with the spindle, something like a capital letter "T." One of these little arms is solid, but the other is hollow, and the cotton enters the top, passes down

the hollow arm, and then, from the bottom of it, to the bobbin. Now it is easy to see that the revolving of the centre spindle, which with its two arms constitutes the fly, has the twofold effect of twisting the cotton and also

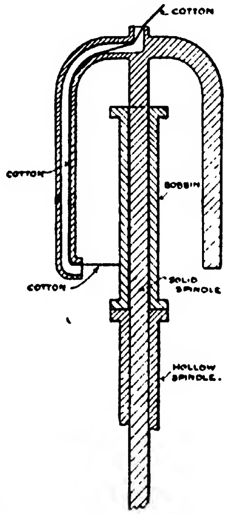


Fig. 62. This shows another of the great fundamental ideas underlying the complicated machinery of a cotton mill.

The bobbin is fixed to the top of a hollow spindle. Through the centre of both passes the solid spindle. At the top of this are the two arms, one of which droops down on either side and which form the "fly." The cotton enters the fly at the top, passes down one arm, which is hollow, and thence goes to the bobbin. As the fly turns rapidly round it simultaneously twists the cotton and winds it on the bobbin. As this goes on the bobbin slowly moves up and down so that the cotton is wound on it with perfect regularity.

winding it on the bobbin. If you find any difficulty in realizing this action, just think of it for a moment as if the end of the cotton were fixed to the fly, just at the top of the spindle; then it is easy to see how the twisting would take place, and the action is exactly the same when the thread of cotton is not fixed, but is passing through the

hollow arm to the bobbin. As this goes on, the machine automatically moves the bobbin up and down, so that the cotton is wound upon it as regularly as upon the familiar reels from the draper's shop. Moreover, at the same time, the machine is rotating the bobbin round so that the cotton may be wound on to it at exactly the right speed; and it automatically regulates this speed according to the amount of cotton which is already on the bobbin; for it is easy to see that one revolution of a bobbin nearly full will wind on considerably more cotton than a single revolution of one which is nearly empty. In this operation, also, the mixing process goes on, though henceforth it is called "doubling," for there are two cans at the back of the machine for each of the flies, and the two strands of cotton, one from each can, unite at the rollers and pass together to the flies, where they become twisted into one. The bobbins, when full, are taken to another fly frame, where the cotton is again doubled, twisted and wound on fresh bobbins.

After the cotton has passed through a number of these machines it has, of course, been very much reduced in thickness, in spite of the fact that in each operation two threads are twisted into one. Moreover, the twisting which it undergoes keeps on adding strength to the strand. The final finishing of the yarn, however, is done by another kind of machine, known by the name of a "mule." The operation of this is really, in principle, very similar to that of the flies, but in detail it is a little different, and this difference makes it more suitable for the final operation. As before, there is a frame with long rows of bobbins upon it, and also more stretching rollers. Instead of the flies, however, there are a number of little

steel spindles, and these are not fixed on the machine like the flies, but are placed on a separate travelling frame, which is able to move backwards and forwards some 5 or 6 feet, upon rails. The whole machine is usually about 100 feet long, and accommodates about 1000 spindles, and it is the number of these spindles which denotes the size and capacity of the mill. A good-sized mill in Lancashire

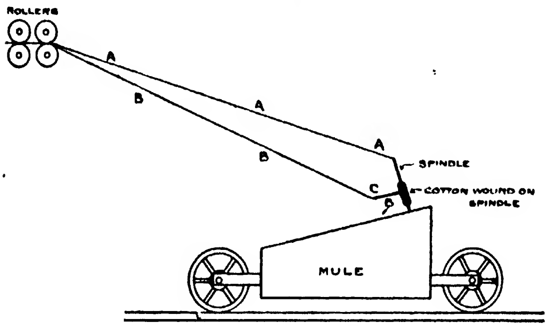


Fig. 63. This diagram shows the working of the "mule," the machine which produces the finished yarn. It moves backwards and forwards on rails. As it goes backwards the yarn is in the position A A A. It then slips off the end of the spindle as the latter rotates, and so is twisted. Then the mule returns forward, and at that time a guide depresses the thread at C so that it takes the position B B B and is wound on the spindle. Thus as the mule retires it twists the cotton; as it advances it winds up the length just twisted.

will have 100,000 spindles, and the cost of the mill and all the details as to production and so on are generally spoken of as so much per spindle.

Now the action of this mule can be seen from diagram Fig. 63. On the left are shown the stretching rollers, which you must please assume are mounted upon a frame with the bobbins to supply the material to them close by. We will imagine that at the moment the mule is close up against the frame, and we will watch the

operation of one individual spindle. The latter, as you will see by the diagram, leans a little *towards* the rollers, and it rotates at a speed of about 10,000 revolutions per minute. Now the first operation is to give the final twist to the yarn. The rollers commence to pay the yarn out, and the spindle to which it is attached twists it round its upper end. It appears from this as if the only result would be to wind the cotton round the spindle, but owing to its slanting position the cotton slips off the end, and so it becomes twisted instead. You can easily illustrate the action for yourself by winding a piece of narrow tape round one finger and then allowing the twists to slip off the end of your finger. You will then notice that the tape is twisted, and consequently the first action of the spindle is to twist the cotton; and as the rollers pay it out the mule, carrying the spindle, of course, with it, retreats some 5 or 6 feet. Then, quite automatically, a change takes place. The rollers stop, the mule commences to approach the frame again, and as it does so a wire guide descends and depresses the cotton so that this time it really is wound round and round upon the spindle. So the operation goes on, the mule alternately receding from and then approaching the frame. Every time it recedes it twists, every time it approaches it winds up upon itself the length of yarn which it has just twisted. The lower part of the spindle is covered by a tube of paper which is slipped on to it, and it is on to this tube that the cotton is wound. When a tube is filled it is slipped off the spindle and is taken away to the warehouse, the finished article, ready to be put on the market.

The testing and weighing of the cotton after it is

finished is an interesting operation. The little paper tubes with the cotton wound on them are, I might say, known by the curious name of "cops," and from each batch of them samples are taken to ascertain that they are of the right strength and thickness. The standard length, as we shall see presently, is 840 yards, and a convenient fraction of that for testing purposes is 120. The man who does this work, therefore, has a little drum which he can revolve at a high speed by turning a handle. He fixes one end of a piece of yarn to this drum, and then spins it round by means of the handle, until an indicator on the machine shows him that he has got 120 yards upon it. Then he stops and slips the cotton off the drum, endwise, so that he has it in the form of a skein, which he places over two hooks. The lower hook is drawn down by machinery, while the upper hook is attached to a spring balance. As the lower hook descends the skein becomes stretched between it and the upper one until it breaks, and the spring balance shows the force in pounds which was required to break it. Thus is found the strength of the cotton. The skein is then weighed to see if the cotton is the right thickness. Thicknesses in yarn are denoted by the term "counts"; that means the number of times 840 yards will go into a pound. For instance, the particular size of yarn spoken of as 60's means that 60 times 840 yards will make a pound of cotton, and if you care to work this out, you will find that 1 lb. of such cotton will reach the length of close upon 30 miles.

There are one or two little incidental inventions in connection with the cotton mill which are interesting in themselves. Perhaps the most interesting of all is the

method of covering the rollers. You will perceive from the earlier description that there must be an immense number of these, amounting to hundreds of thousands in a large mill. They consist of a steel roller with a layer of felt round it, and finally a tube of thin leather, slipped over the felt. You will easily see, too, that they need to be very uniform in size, for if there were any hollow places in them, however slight, they would allow the fine yarn to slip, and, of course, no leather (being a natural product) is absolutely uniform in its thickness. It is usual, therefore, for one man to be employed continually in recovering rollers. He makes the tubes of leather by turning a sheet of leather round a model roller and carefully glueing the edges together. Then this tube, when the glue has dried, is forced on to the roller, after which it has to be made quite true. For this purpose it is put into a little machine something like a lathe, in which it is turned round, while at the same time a little steel disc, which is covered with sandpaper, rotates at a high speed against it. This steel disc travels backwards and forwards from end to end, until it has rubbed down the leather to exactly the same thickness throughout and made the roller perfectly cylindrical.

Finally the ends of the leather have to be trimmed off so as to remove all rough edges, and this is done in a manner which is highly original. The roller is put on to a machine which causes it to rotate at a very high speed indeed, and while it is turning a piece of wood is held against the edge of the leather tube. This causes great friction between the leather and the wood and generates great heat, sufficient, in fact, to *burn* all the rough edges away and make the ends quite smooth.

The cotton mills have a method of driving their machinery almost peculiar to themselves. Near the centre of the mill, or sometimes at one end, there is a huge, narrow chamber, extending from side to side and from the ground to the roof, known as the rope race. The machines on each of the floors are driven by a steel shaft which runs from the rope race, through the wall, and then the whole length of the floor, and at the end of this shaft, in the rope race, is a large iron pulley with grooves cut into it. The engine room is an enlargement of the rope race on the ground floor, and the engine, which is often of great power, 1000 horse-power or more, has a large fly-wheel, in which there are also cut a number of grooves. From the fly-wheel of the engine to the pulleys on the ends of the shafts stretch powerful cotton ropes, and thus the power from the engine is communicated to the different floors. The power from the shafts to the machines fixed in the different rooms is conveyed by leather bands in the manner with which most people are familiar, but for what is called the "main" drive, that is to say, from the engine to the shafts, this is almost invariably done by means of ropes, and a truly impressive sight it is to see the large number of moving ropes passing up into the rope race to the various floors of a high building.

Another feature of the cotton mills in Lancashire, or at any rate of the more modern ones, is a tower. The buildings are generally five or six storeys, and the tower is considerably higher still. Now this is not merely for the sake of ornament, as one might suppose; it is built for the purpose of holding a large water tank to supply the sprinklers with which the mill is fitted. Pipes run from

this tank all over the building, having at intervals little outlets, which are closed by some kind of plug held in by a rivet of lead, or some other material which easily melts. The reason for this is that there is necessarily a great deal of fine cotton dust about a cotton mill. It is continually being swept up, but still there is a great deal of it always about, and it is highly inflammable. Moreover, with such a vast quantity of high-speed machinery it is easy to get something heated up to such an extent that it is able to set fire to this cotton dust, and consequently cotton mills are very liable to damage by fire. Now the moment a fire occurs in a mill fitted with sprinklers these lead rivets melt away, the plugs fall out, and the water begins to spray upon the fire. This apparatus is so effective, that a mill so fitted can be insured against fire for a very much smaller premium than one without it.

In some of the older mills, where they have no high tower upon which to fix a tank, the same result is attained by having at a lower level a strong enclosed tank, something like a steam boiler. This is partly filled with water, and then compressed air is pumped into the other part. The compressed air has sufficient power to force the water out of the tank up to even the highest floor in the building, so that it sprays upon a fire just as it would do if it came from an ordinary tank placed on a high level.

CHAPTER XVIII

THE INVENTION OF THE STEAM TURBINE

As I have already remarked, the first steam motor was a turbine. Yet the steam turbine is the latest development of the steam engine. The reason for this apparent contradiction is, that the turbine of old lacked a certain essential feature, without which it was too inefficient to be of any use.

To understand the working of a turbine we need to realize the difference between pressure and velocity. The reciprocating engine is driven by the pressure of the steam pushing against the piston. In the turbine the pressure is only employed to give velocity to the particles of steam, so as to cause them to strike forcibly against the moving parts of the machine.

Most of us have played with an air gun. A part of such a weapon is an air pump, and in the act of loading it we cause this pump to compress air into a little chamber. There the air is under pressure. The moment you pull the trigger it is liberated into the barrel, where it loses its pressure, but from which it rushes with great velocity. The pressure is changed into velocity in the barrel.

If you put your hand under the mouth of the domestic water tap, so that no water can get out, and then open the tap, you will perceive the water pressing against your hand, and you will easily comprehend how it would push against a piston were there such a thing fitted in the bore of the tap. Afterwards, move your hand to a little distance,

but hold it so that the jet of water strikes it as it emerges from the tap. Then you will feel the same water, with the same force behind it, but acting in a different way. The first will be a case of water acting by pressure, while the other will show it acting by its velocity.

The force with which the jet of water strikes against your hand is due to the combined force of all the tiny particles of which the water is formed, each doing its share and deriving its energy from its weight and the velocity with which it is shot out of the tap.

Now the force with which any moving body strikes another is due to these two things: its weight and its speed. In the case which we are discussing we are concerned with the behaviour of particles of steam under various conditions, and since they all weigh the same, we can, for our present purpose, dismiss weight from our minds and think only of the question of velocity. In comparing the striking force of a cannon ball and a rifle bullet, for instance, we should need to consider both weight and speed, but if we are comparing a number of bullets of one particular size and weight, then velocity alone matters.

Let us consider the case of one particular water particle from our tap. As soon as the tap is opened it is shot out because of the pressure of water behind it. The speed will be great or small as the pressure is great or small, and so we see pressure and velocity are related. As soon, however, as it gets clear of the tap, since its course is downwards, gravity pulls it and increases its velocity; therefore, if you hold your hand a foot below the tap, it will be hit harder by the particle than if you hold it an inch below. Now please observe this: the initial velocity

is due to the pressure, but the added velocity which is felt lower down is due to gravity, another force altogether. The same applies to all the particles which go to make up the jet, and so we may say that the force with which a jet of water strikes an object will be in proportion to (1) the velocity of the particles, and (2) the number of those particles which are there; in other words, the quantity of water.

The same applies if the water is in its vaporous form, which we call steam. The particles are just the same, only the heat has developed within them a mutual hatred, which causes them to keep a greater distance apart; and, moreover, leads them, if they are free, to place the greatest possible distance between each other. A jet of steam is, up to a point, just the same as a jet of water. It consists of water particles, travelling with great velocity, and its hitting power depends upon the number of particles and their velocity, just as in the case of the water jet.

Now it is common experience that if a moving body strikes another body, either stationary or moving at a slower speed in the same direction, it will tend to impart movement to it; or, if it be already moving, increased movement. This is why a windmill is turned by the wind. The moving particles of air strike against its sails, and although the sails are infinitely heavy compared with the weight of a particle of air, there are so many of the latter that they are able to move it.

If we substitute particles of water for particles of air, and direct them with great velocity against blades or vanes set upon a wheel, somewhat after the manner of an up-to-date windmill, the wheel will be driven round.

The first necessity, then, is to impart to the particles of water (or steam, we will say for simplicity, though it must be understood that a particle of steam and a particle of water are just the same) the utmost possible velocity. Then we shall be able to construct an efficient steam "windmill," or steam turbine.

It is this development of the greatest possible velocity which baffled the old experimenters. They got the

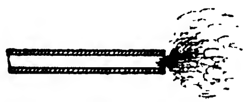


Fig. 64. If steam issue from a plain piece of pipe, the expansive force within it simply causes it to "scatter" as soon as it gets free.

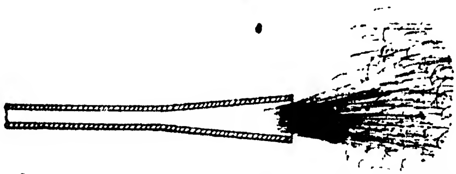


Fig. 65. If a taper nozzle be added to the pipe the expansion will take place in the nozzle, resulting in the particles of steam being shot out with greatly increased velocity.

velocity due to the boiler pressure, but little more. We saw just now, in the case of the water jet, how the pressure of the water produced *some* velocity, which had afterwards added to it that caused by gravity. In the case of steam we also have an additional *procurable* velocity, over and above that due to the boiler pressure, namely that due to the internal elasticity of the steam itself, that expansive force which we use in the compound engine.

If we let the steam issue from a simple nozzle with parallel sides, a plain piece of tube, in fact, we get the velocity of the boiler pressure and a little of the expansive

force too, but since the moment the steam gets free from the end of the nozzle it expands freely in *all directions*, the expansive force is largely dissipated. If, however, we make the nozzle to taper outwards, the steam, as it reaches the mouth, expands, and the expansive force acting in the taper chamber causes all the particles to be shot out at the end with enormously increased velocity. For example, with a pressure of 200 lbs. per square inch and a plain nozzle, the steam would issue at a speed of about 1800 feet per second, but with a well-designed nozzle, able to convert the maximum proportion of expansiveness into velocity, the speed would be over 4000 feet per second, or about 45 miles per minute.

And now we can turn to a concrete example. The first successful steam turbine was made by the Hon. C. A. Parsons, in the year 1886, but for purposes of explanation it is best to start with one of a little later date, and turn to the Parsons turbine again later on. In the year 1889 a Swedish engineer, named De Laval, who was interested mainly in dairy machinery, needing a very small, compact engine of high velocity, made experiments to see whether a wheel with teeth or blades fixed to it could not be blown round by a steam jet; and he discovered that by shaping the nozzle from which the steam emerged in the way I have just described, he got a really efficient machine, which compares well with the efficiency of reciprocating engines.

The wheel is of comparatively small diameter, being made as small as 4 inches, while 3 feet would be a large size. It is strongly built, and to its edge are attached a large number of little curved blades, radiating from the centre like spokes. This is enclosed in a case, through the

end of which several nozzles project. The illustration Fig. 66 will explain this better than many words. The steam jets from these nozzles strike against the blades, which are so shaped that not a single particle can miss them, and so they absorb nearly the whole of the energy which the steam possesses.

This transfer of energy from one body to another is a

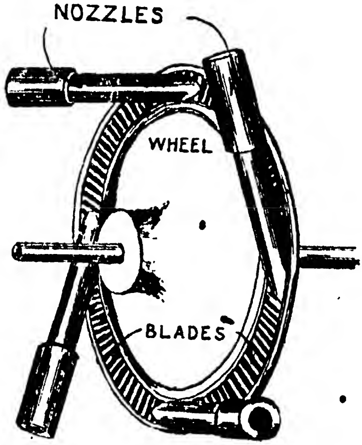


Fig. 66. This shows the simplest form of the impulse turbine.

little puzzling at first, but it can be made clear by a homely illustration. Most people have at least watched a game of billiards, even if they have not taken part in it. If a billiard ball be struck with the cue just in the centre, so that it is practically free from "spin," and directed accurately so that it hits another ball exactly in the centre, or "full," as the billiard player calls it, the first ball will, after the impact, stop dead, while the second, which was still, will move on with exactly the same energy which the first one had when it struck it.

In other words, the energy of the one will have been completely transferred to the other. In the turbine the direction of the shooting particles of steam should be such, and the blades must be so formed, that the energy of the particles is almost entirely given up to the blades, just as the energy of the moving ball was given up to the stationary ball.

In practice we cannot make the stream of particles to strike the blades full and square. It is physically impossible to construct such an arrangement. The impact must take place, more or less, at an angle, and so the result is more like what happens when a billiard ball hits

Fig. 67. The action of steam in a turbine illustrated by billiard balls.
Arrow 1 shows direction of strikers ball, before the impact.
" 2 " " object ball, } after the impact.
" 3 " " strikers ball, }

another not quite "full," but about as indicated in the diagram Fig. 67. Then the striker's ball does not give up quite all its energy to the object ball, but has enough left in itself to roll a little way in a diagonal direction, as shown by the dotted line. The distance which the ball will travel in that direction will be a measure of the amount of force left in it after the collision.

In the same way, the energy with which the steam rebounds, as it were, after striking the wheel will be a measure of the force which it has retained in itself after the encounter, and if that is shown to be small, it is evident that a very large proportion has been transferred to the wheel. In the Laval turbine the steam leaves the wheel with scarcely any perceptible force at all, and so

we can see that the particles of steam, each acting after the manner of the billiard ball, have given up to the wheel practically all their energy.

In order to do that, however, the blades must move at about half the speed of the particles, which, as we saw just now, may be as high as 4000 feet per second. In practice one-third is about the usual speed, but even then, in the small sizes particularly, the speed of rotation is enormous, varying from 10,000 to 30,000 per minute. This is rather inconvenient, since it necessitates the use of reduction gear, a small tooth wheel, that is, driving a larger one, and that means loss of power through friction. It also seemed likely at first to make the machine impossible altogether; for the most accurately made wheel is not absolutely perfect in balance, and at that high speed the slightest inequality set up such severe vibrations that the machine would have lasted but a very short time. The inventor, however, got over his trouble in a way which leaves nothing to be desired. He put the wheel upon a shaft which was comparatively long and thin, so that it could bend slightly. This enables the wheel to find its own true centre, about which it is in perfect balance, and having found that, it revolves as sweetly as can be wished. This idea was, I believe, quite original, and had never been used before in any machine of any kind; and this fact, combined with its simplicity and the perfect manner in which it achieves its object, entitle its inventor to a very high place in the regard of those who can realize the worth of an invention.

That, then, is the simplest of all the varieties of steam turbine. Just a wheel with blades on its edge, blown by jets of steam from expanding nozzles; the whole being

enclosed in a case, from which the exhaust steam may be allowed to escape to the atmosphere or to a condenser, whichever may best suit the particular conditions.

From the Laval it is natural to pass to the Rateau, for the latter is really not much more than a number of Laval turbines working together, the exhaust steam from one driving the next. The wheels are all fixed upon the same shaft, and each is enclosed in a separate chamber in one casing. The nozzles are formed in the partitions between the chambers. There are usually from twenty to thirty wheels.

At first sight this seems but a needless complication of a simple machine, but it is not so; for it overcomes that great objection to the Laval machine, its terrible speed.

The speed of the steam is roughly proportional to the pressure. At 200 lbs., as we have seen, it is 4000 feet per second. Now suppose we have a Laval machine, and supply it with steam at this pressure. If we provide a large opening for the exhaust steam, it will escape freely, and there will be no pressure inside the case. The full 200 lbs. will then be available to give velocity to the particles, and the tendency of the liberated steam to expand in the nozzles will be free to exert itself fully. Thus we shall get the extreme possible velocity. Suppose, however, we partially close the outlet for the exhaust steam. We shall then get a pressure in the casing of the turbine, for although the steam will escape, it will not do so freely. By adjusting the outlet we could make this internal pressure, say, 150 lbs. Then the steam will emerge from the nozzles, not into the free, open atmosphere, but into an atmosphere of steam at 150 lbs. pressure. For practical purposes, then, the steam will only be at 50 lbs. pressure and not

200 lbs., and its velocity will be reduced accordingly. The wheel can then be driven at a much slower speed without sacrificing efficiency; but, of course, a machine so arranged would be capable of much less work than if it were arranged to take advantage of the full steam pressure.

We can, however, overcome that disadvantage without much difficulty, for the exhaust provides us with a supply

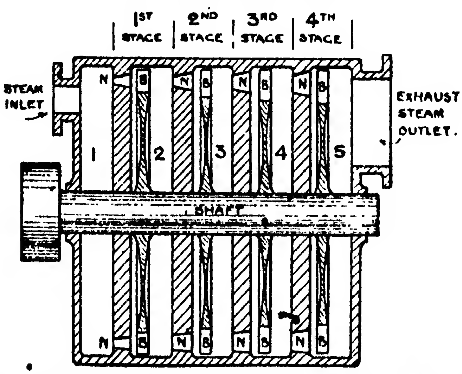


Fig. 68. Elementary impulse turbine of four stages. The steam enters chamber 1, passes thence through the nozzles N to chamber 2 striking the blades B on the first wheel as it enters. In like manner it passes in succession through each of the other three stages.

of steam at 150 lbs. pressure, which we can take to another turbine, where we can let it down in the same way to 100 lbs., and from that we can take it to another and let it down further to 50 lbs., finally taking it through a fourth, so as to use the last of the expansive force which it possesses.

Thus, instead of letting the steam expand to its full extent all at once, and making it do all its work straight away, we let it expand by four stages, doing work at each stage. By that means we are able to make full use of the

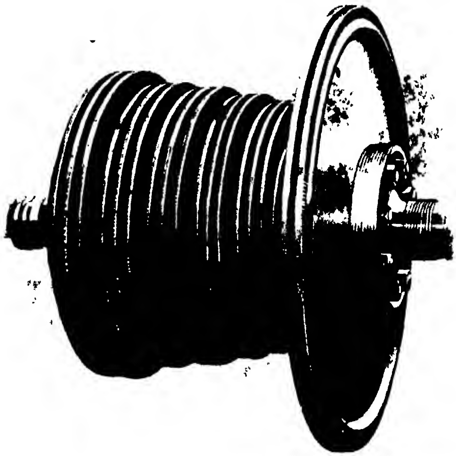
velocity of the steam, without reaching that excessive speed which is the drawback to the Laval machine.

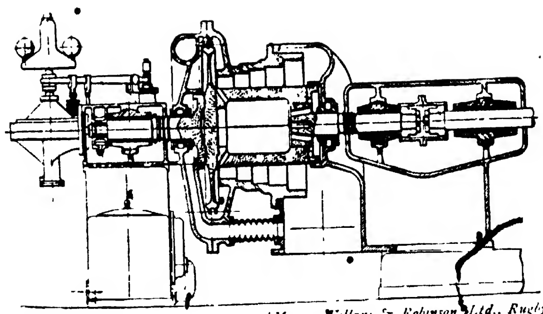
Instead of using four separate machines, we should make them all into one, on the lines indicated in the diagram Fig. 68. Each wheel with its nozzles is called a stage, from the fact that the steam is expanded "in stages," instead of all at once.

The Zoelly turbine is similar to the Rateau, but is different in some of its details, and usually has fewer stages.

The Curtiss turbine, which probably shares with the Parsons the leading position in the turbine world, is a little more elaborate.

In the Laval, the Rateau, and the Zoelly machines there is only one ring of blades set around the circumference of the wheel, but in the Curtiss the wheel is broader on the rim and there are generally two rings of blades. The particles of steam shoot out of the nozzles, strike the first ring, and deliver up to them a part of their energy, but not all. They rebound off the blades in this ring on to a second ring of blades fixed to the casing, but not attached to the wheel at all. These blades have no other function than to guide the particles on to the second row of blades upon the wheel, and to these latter they give up the rest of their energy. At first sight this seems wasteful, for surely the steam must give up some of its energy to these fixed blades, which, since they are fixed, do not add in any way to the power of the machine. This is a mistake, however, and the explanation is that a body struck by another does not absorb the energy of the striking object, unless it is moved by it. We used the simile of two billiard balls to illustrate the transfer of energy from one moving object to another, but that would





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HOW A STEAM TURBINE WORKS

These two photographs show the working of the "Willans Disc and Drum" Turbine, a combination of the two kinds of Steam Turbine. The upper photograph shows the Rotor or rotating part which the steam blows round. The lower one is a section of the complete machine showing the Rotor in its place.

not have applied if the struck ball had been fixed. When a ball, for example, strikes the cushion, which is immovable, the cushion absorbs nothing, and the ball simply rebounds with the same force that it had when it struck the cushion. One is apt to think that this is a property peculiar to the indiarubber of which the cushions are formed; but that it is not so can be seen from the fact that a solid glass marble, if dropped upon a hard floor,

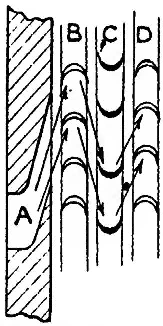


Fig. 69. HOW THE STEAM BEHAVES IN A CURTISS TURBINE.
It enters the nozzle A, expands there and shoots out in the direction of the arrow, strikes the blades B, rebounds on to the stationary blades C and from them on to the blades D. Thence it goes through more nozzles to the next "stage."

will rebound to almost the same height as that from which it was dropped. The particles of steam, therefore, lose little through having to be directed into their path by the blades of the fixed ring, and it is only to the moving rings, those which are fixed upon the periphery of the wheel, that they give up their energy. The course of the steam particles through the nozzle, and then on to the successive rows of blades, can be seen very clearly in Fig. 69. Curtiss turbines are made with two, three, or four stages, the expansion, be it noted, taking place only in the nozzles.

CHAPTER XIX

THE PARSONS TURBINE

The Curtiss turbine is used by the United States Navy for the propulsion of large ships, and at least one large vessel of the British Navy has them. Some of the German naval vessels have the Zoelly, but for marine purposes the Parsons is by far the most largely used.

This, the original of the modern steam turbines, is to a certain extent different in principle from the others; and so, whereas they are called impulse turbines, this is a reaction turbine.

Before I attempt to explain the difference I must, however, remind my readers of the important point to be remembered in regard to the "impulse turbines." The steam, in passing from one stage to another, goes through nozzles, and it is so arranged that it is in those nozzles alone that it can expand. It emerges from each nozzle into a chamber which is already full of steam at its own pressure, and so it cannot expand in the chamber where the wheel is. In our imaginary turbine, described in the last chapter, for example, in passing from the 150 lbs. stage to the 100 lbs., it passes through nozzles so shaped that while it enters them at the higher pressure it emerges at the lower the lost pressure having been converted into velocity. It therefore enters the 100 lbs. chamber only when it is at 100 lbs. itself, and so it cannot expand any more until it gets into the next set of nozzles.

The expansion of the steam, then, takes place in the

nozzles leading to the chambers, but not in the chambers themselves. The particles of steam strike the blades by virtue of the impulse which the expansion in the nozzles has given them. The steam does not (and this is the point) expand at all when in contact with the blades.

In the Parsons there are no separate chambers. There is one large cylindrical casing, and inside it a large cylindrical rotor or rotating part. Attached to the casing there are sixty or eighty circles of blades fixed. On the rotor there are a like number of blades too, so placed that when the rotor is in the case the two kinds of blades will occur alternately; first a row of fixed blades, then a row of rotor blades, then another of fixed, and so on. The steam enters at one end, and is cut up by the first row of fixed blades into jets, which are by the same means directed on to the first row of rotor blades. Rebounding off these, the second row of fixed blades redirects the steam on to the second row of rotor blades, and so on. Thus, instead of expanding in certain definite and distinct stages, the steam is *expanding all the time.* If the case were the same size all along, there would not be the necessary room for expansion, and the machine would, to a certain extent, become "choked" with steam. Therefore the case is enlarged by several steps as it reaches the lower-pressure end, so that there shall be room for the steam to expand as it travels along.

One row of fixed blades and one row of rotor blades form in this machine a stage, being, in fact, a complete turbine, capable of working by itself, apart from any of the others, if need be. It is different from the stages of the impulse machines, you will observe, in that it is not enclosed in a separate case, and so the expansion of the steam is *not*

checked while it is in contact with the blades. Consequently the steam *reacts* upon the blades. In the impulse machine the steam strikes the blades with the velocity which it already possesses. In the reaction machines it strikes the blades in that way too, but it is at the same moment expanding also; and it *springs away from* the blade which it has just struck, not only with the rebound due to the impact, but with a springy energy in addition, due to the expansion which took place while it was in contact with the blade. The billiard-ball analogy is not sufficient here. We need another, and the best that occurs to me is that of an athlete who jumps by means of a spring board. He takes a run and leaps into the air, dropping with his feet upon the spring board. The natural effect of this is to bend the board and so produce a rebound, and without any further exertion on his part, the spring of the board alone would suffice to throw him up in the air. He is not content with that, however, so he takes care to fall upon the board with his legs drawn up under him, so that at the same moment, when the springiness of the board is throwing him upwards, he can suddenly straighten his legs out and so add to the height of the jump by a spring of his own. By so doing he bends the board more, for he presses down upon it with his feet with a force due to two things, first his dead weight falling from a height, and second, the energy of the spring. That second downward push upon the board is the *reaction* of his action in springing.

A common form of punishment in prisons used to be the treadmill. This appliance was a kind of turbine, worked by a stream of human particles. It consisted of a pair of wheels fixed upon the same shaft, connected

together by rungs, like those of a ladder. In fact, it was an endless ladder. The prisoner stepped on one rung, and allowed his weight to push it down a little way, whereupon he stepped on to the next one higher up. Thus he kept it going. If, now, a specially lively prisoner had insisted upon *springing* from one rung to the next, the reaction from his springs would have driven the wheel round with much increased force. That is what the steam does in the Parsons turbine. In addition to hitting the blades with the force of its velocity, it springs away from them again, and the reaction from that spring is added to the force of the "hit." Hence this and similar machines are called reaction turbines, not because they act entirely by reaction, but because the use of the reaction is a feature which distinguishes them from the others.

Some turbines, such as the Westinghouse and the Willans "disc and drum," are a combination of the Curtiss and the Parsons. The steam first passes through a stage of the Curtiss type, and then through many stages of the Parsons type.

At first sight there is a resemblance between the several rings of blades in each stage of the Curtiss and the rings of blades in the Parsons, but they are really quite different in operation. The three rings in the Curtiss are enclosed in a chamber, so that the steam hits the three rings in succession, without suffering any expansion while it is so doing. Therefore there is no reaction in the Curtiss machine.

There are several interesting features in the Parsons turbine. In the first place, it will be apparent to anyone that while passing along from one end to the other, the steam will not only drive the rotor round, but will push

against the enlarged parts of the rotor as if they were pistons, towards the low-pressure end. At first, Mr. Parsons got over this by making twin turbines, as it were, both on the same shaft, the steam entering at the middle, and flowing half to one end and half to the other, so that they balanced each other. That made the machine inconveniently long, however, so later he invented a system of balancing pistons. The diagram Fig. 70

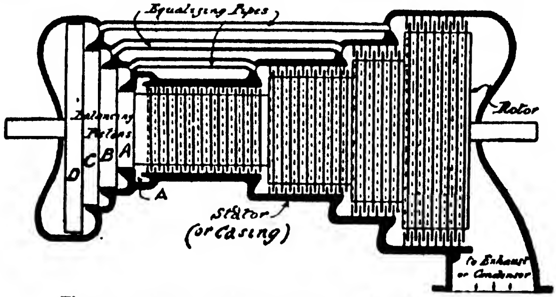


Fig. 70. SIMPLIFIED SECTION OF A PARSONS TURBINE.
The dotted lines indicate the rings of fixed blades, the black lines between them the moving blades. The steam is first admitted to the groove A.

shows these and their purpose very clearly. The steam presses the first and smallest parts of the rotor to the right, so piston A is made of just such a size that the steam will push it with equal force to the left. That part, therefore, balances naturally. Then, in like manner, the piston B is of such a size that the steam, pressing against it towards the left, will balance the force with which it will push the intermediate part of the rotor to the right, and a pipe called the equilibrium pipe is led from one to the other, so that whatever variations may occur in the supply of steam, the same force will always be pushing piston B to the left and the intermediate part of the drum to the right, and so under all conditions

they will balance. Piston C, in the same way, balances the next larger part of the rotor, and so the powerful thrust, which would otherwise occur against the bearings, is obviated, and the friction which would result is avoided.

The pistons do not, of course, go in and out like their namesakes in the steam engine. They simply rotate, and the friction which they would cause if they fitted closely, as the ordinary engine piston does, is removed by the use of labyrinth packing. A little space is left between

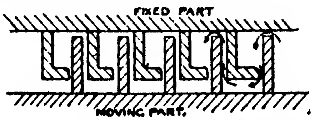


Fig. 71. This is an ingenious "Labyrinth" packing which practically prevents the steam passing between the fixed part and the moving part, yet does not require that they should touch each other.

the piston and the hole in which it works, and rings of steel of curious shape are fitted in this space, the rings being fixed alternately to the piston and to the casing. The form of this can best be seen from Fig. 71, and it will be observed that although there are clear spaces through which the steam can pass, it has not got a straight course open to it, but must, if it gets through, be continually turning corners. The consequence is that at each turn it tends to form eddies among the rings. Put briefly, the passage among these rings gets choked up with steam, which can only pass through with great difficulty, and so very little at all passes; yet, since there is no actual contact between the rings, there is scarcely any friction.

In some of the impulse turbines similar labyrinth packing is used at the places where the shaft passes through the partitions between the stages.

The question will naturally arise in the reader's mind as to what are the relative advantages of the different

types. And the question is a very difficult one to answer, since each has its devotees. Some of the chief points of comparison may, however, be referred to. The Parsons, for instance, is rather long, and so takes up a lot of room compared with the others. The Laval needs, under almost all conditions of working, a mechanism to reduce the speed.

One very important difference between the impulse and reaction machines is a purely practical one, and is mentioned here mainly to illustrate the fact that in putting an idea into operation there are generally practical difficulties arise which are quite unsuspected by those not in the business. In the impulse turbines the steam shoots in a jet into a chamber full of steam at the same pressure as itself. The only force, then, which animates the steam is the momentum, and that acts *in a straight line*. Consequently a space may be left between the ends of the blades and the casing, and the steam will not have any tendency to pass through it without hitting the blades.

In the reaction machines, however, the pressure is continually falling, so that the steam is continually being *sucked* towards a region where the pressure is lower. This suction is, of course, in addition to the momentum of the steam jets as they leave the fixed blades, and it causes a tendency for the steam to seek the easiest path, avoiding the blades if it can. Therefore the rotor blades must nearly touch the casing, and the fixed blades have to be very close to the rotor, so that there shall be the least possible space for the steam to leak through. This space is so small that a slight variation due to a change in temperature, or a slight bending of the rotor, will sometimes cause the blades to come into actual contact with something, causing them to be "stripped" off and the

machine badly damaged. It has taken the greatest care and skill on the part of the designers to so form both rotor and casing that the temperature variations and the springing of the rotor shall not cause this to happen. It has been done, however, and " stripping " does not now often occur, even though the blades are revolving within a very small fraction of an inch from each other.

The speed at which even the slowest turbine works necessitates ample lubrication. Oil is generally forced through the bearings by a pump in such copious quantities that it will not only lubricate in the ordinary sense, but cool the bearings. The same oil is pumped through over and over again, and at one point in its course it passes through a coil of pipe exposed to the atmosphere, or some similar contrivance, the purpose of which is to cool it and so ensure that the bearings shall always be supplied with cold oil.

The Curtiss machines for driving dynamos are often placed with the shaft vertical. The rotor thus spins round in the same position as a boy's top, and so the weight of the rotor, and also of the rotating part of the dynamo, is carried on the bottom end of the shaft, in what is called a " footstep " bearing. This bearing is lubricated with water. Water is pumped into the bearing under the end of the shaft at high pressure, thereby lifting it up slightly, so that it turns not upon solid metal, but on a film of water.

Turbines are governed by governors generally of the centrifugal type so familiar on steam engines. They are, however, usually more elaborate, since with such high speeds as are normal in even the slowest turbines any considerable increase would be a very serious matter.

When employed in driving dynamos turbines are often governed electrically as well. The force or voltage generated by a dynamo depends upon its speed. If the turbine driving a dynamo were to exceed a proper speed the voltage of the current would go up, and that can be made to check the speed or even, if the increase be beyond a certain point, stop it altogether.

These machines are, in fact, generally governed in two ways. One governing apparatus tends to keep the speed constant, while the other, the "emergency" governor as it is called, normally remains idle. If, however, for any reason there should be a sudden increase in speed which the ordinary governor cannot cope with, then the emergency governor comes into operation and cuts off the steam entirely.

In large machines the emergency governor operates through a "relay." That is, it controls a small current of steam in a small pipe, and that current in turn, working upon a piston in a cylinder, opens and closes the large valve which controls the entry of steam into the turbine.

The ordinary governor is sometimes made to act in a curious way too. We are already familiar with the fact that if steam be throttled, that is to say, made to pass through a contracted orifice such as a partly closed valve, a waste of energy occurs. This is obviated in the case of reciprocating engines by varying the moment of "cut-off," as I have already explained. There is no cut-off, however, to vary in the turbine, so something analogous has to be introduced. There is a valve operated by the turbine itself which lets the steam in in gusts, and the governor operates by varying the length of the gusts and the intervals between them. If the machine be going too

fast the intervals are increased and vice versa. Thus the steam always enters at its full pressure, and the loss of energy is avoided. In impulse machines the speed is often governed by partially or entirely closing some of the nozzles.

Finally, I should like to mention one or two points where the turbine in all its varieties scores over the reciprocating engine. First of all, the motion is always in the same direction. The parts of an ordinary engine which move to and fro need to be reversed at every stroke, and energy is consumed in doing this. Then there is less friction, for the only places in a turbine where two metal parts come into contact is in the bearing at each end of the shaft. On the other hand, there is friction of steam against metal as the steam rushes through the nozzles and among the blades, but the use of superheated steam largely reduces that. Saturated steam, even if dry, when it enters the turbine, becomes wet as soon as it does work, for the heat used in doing the work is taken from the steam, and it partially condenses. But for the latent heat it would condense entirely; but even as it is a certain amount of water in its liquid state becomes mixed with the steam as soon as it begins to work. If it be superheated, however, the extra heat prevents this to some extent, and as dry steam causes much less friction against a solid object than wet steam, superheated steam is generally preferred in turbines.

Another thing is that the steam always enters at one end and passes out at the other. The fall in temperature which occurs when the steam is allowed to expand in an ordinary engine, and which causes condensation of the live steam entering for the next stroke, does not occur in the turbine.

Finally, the expansion of the steam can be carried out

more completely. One of the difficulties, as I explained earlier, in making full use of the expansive force of the steam in a cylinder is that when expanded fully the steam would take up so much room that the "low-pressure" cylinder would have to be enormous, and the valves would be so large that they could not be opened and closed quickly enough. In the turbine, however, the steam can be expanded without difficulty, until it has no more force left in it than has that which we see rising from the spout of a tea-kettle. No valves are needed, and the casing of the turbine can be easily enlarged at one end as it is in the Parsons, until it is big enough to hold the steam after it has undergone complete expansion.

It must not be thought that there is any very *striking* difference in the amount of steam consumed for a given horse-power between a good reciprocating engine and a good turbine. The difference is only slight, but still its influence on the coal bill is sufficient to make the question of which shall be used a matter for careful consideration. Generally speaking, the Parsons seems to be the best turbine in large sizes, and the impulse turbine in the small sizes. Up to about 500, or even 1000 horse-power, however, a good reciprocating engine can beat the best turbine, as far as economy is concerned. They run well, however, in double harness, for the reciprocating engine makes good use of the steam while at the higher pressures, while the turbine does best at the lower pressures. Therefore a reciprocating engine, taking the steam direct from the boiler and passing its exhaust on to a turbine, makes a very good combination.

In many works where there are large reciprocating engines it pays to instal turbines to work with their exhaust steam.

CHAPTER XX

MINOR HEAT INVENTIONS

BESIDES the heat engines, there are a number of other interesting inventions which well deserve mention. I have called them "minor," but they are only so by comparison with the heat engines, which are of such paramount importance. They are, on the contrary, of considerable value in themselves.

First, one may refer to the apparatus for the heating of large buildings, since that is a matter of personal interest to most of us. Moreover, if anyone should be disposed to criticize the inclusion of such a thing as a hot-water heating apparatus in this book of Mechanical Inventions, I would remind him that it is no less a piece of mechanism because the working part consists of water. The heat in such an apparatus is conveyed not by any mysterious "scientific" means, such as radiation, but by the actual mechanical movement of the water. There are several systems of heating by hot water, but they all depend upon the movement of the water, as I have just remarked.

There are three ways in which heat may be carried from one place to another. One is radiation by means of ethereal waves, the outstanding example of which is the passage of heat from the sun to the earth. Another is called conduction, since the heat is *conducted* by some medium, such as a metal. The handle of a metal teapot

becomes very hot, because the heat is conducted from the hot tea to the handle by the metal, which is a good conductor. Moreover, if it be a metal handle it will part readily with its heat to the hand and so feel more hot than it really is. On the other hand, an earthenware teapot will get much less hot in the handle, for earthenware is a bad conductor. Generally speaking, good conductors of electricity are good conductors of heat, and vice versa, an instance of the relation between electricity and heat.

The third means is convection. The heat is then actually *conveyed* from one place to another in a hot substance. The old warming pan with which our grandmothers used to heat the beds on a cold night is an example of convection. The heat resided in certain hot coals, and these were carried bodily in the pan, heat and all. Deposited in the bed, they gave out their heat, and so the heat was conveyed from the fire to the bedroom.

Water, as I have pointed out already, is a very bad conductor. Therefore a heating apparatus which works by hot water must use the convection method.

The plan most usual nowadays is called the low-pressure system. At some point, generally in a cellar, there is a boiler. In large installations it may be a " Lancashire " or a " Cornish " boiler, but in moderate-sized ones it is generally of cast iron. These cast-iron boilers are made in sections, so that they can be built up to any size, within reason, of course. There is a front section and a back section, and between them you can put as many intermediate sections as may be required, the whole being held together by long bolts passing from back to front. When put together these form really a double box. In the inner box is the fire, while between it and the outer one is

the water. Thus there is a large heating surface, and such boilers are quite economical. Then, from the top of the boiler, there rises a pipe. This is carried to a distance through or around the building to be heated, returning eventually to the bottom of the boiler. The heat causes the water to rise and flow up the pipe at the top, returning, after it has become chilled by its journey round the building, to the bottom. There may, of course, be any number of these circuits, so long as the boiler is large enough to supply them with heated water.

The heat escapes from the pipes into the building mainly by heating the air in contact with them. Air is, like water, a bad conductor; but that in contact with the pipe having been heated rises and gives place to other colder air, so that convection is set up and the heat is distributed by these gentle currents of slightly heated air.

At intervals the well-known "radiators" are often placed. These are really only sets of pipes through which the water passes, and their purpose is to present to the air an additional amount of surface from which it can pick up the heat. They do not really "radiate" heat to any great extent, but work mainly by heating the air by conduction and convection combined, just as the pipes do.

The boiler and pipes are always full of water, being kept so by means of a pipe, called the expansion pipe, which runs up to a high point in the building well above the highest point in the hot pipes. When the water is heated it expands, and some of it is pushed, by the expansion, up this pipe. It terminates in a small tank—the expansion tank—fitted with a ball-tap such as we have in our houses, so that it and the whole system of piping is always full.

It is impossible with a system such as this to raise the water to a very intense heat. The pressure in the boiler is only that due to the height of the expansion tank, and supposing that to be, for example, 40 feet high, the pressure would be about 20 lbs. per square inch. If, then, the water were heated to over 259 degrees it would begin to generate steam, and this might blow the water up the expansion pipe, thereby throwing the whole thing out of order. Therefore 259 degrees is the maximum under such conditions. In the high-pressure system this is overcome. There there is no boiler; but the pipes, instead of being of cast iron and of 3 or 4 inches diameter, are only an inch diameter and of steel. They are fitted together, too, very carefully and strongly, so that they can resist great pressure. Instead of having a boiler the pipe itself is carried several times round a brick furnace. The whole system of piping is filled with water and then hermetically sealed. It needs no attention; the fire has simply to be lit and the water will circulate. Moreover, since the pressure may be very high without bursting the pipes, they can be made exceedingly hot. There is no safety valve or other device to relieve the pressure should it become too great, but instead the whole piping is tested by hydraulic pressure to 2000 lbs. per square inch, a pressure which is not likely to be reached in working.

To provide against the possibility of an explosion in this system, another one was invented called the medium-pressure system. It is just the same as the other, but it has a safety valve. This valve is fixed in a small expansion tank, and is loaded to a certain pressure per square inch, say 500 lbs. The expansion of the water thus finds an outlet, and when the fire is put out and the apparatus

cools, it can suck back, through a small non-return valve, a quantity of water, to make good that which in its hot state it forced out through the safety valve.

In the low-pressure system it is sometimes difficult to keep the temperature in the boiler at a constant level. Several ways have, therefore, been invented of making the boiler regulate itself automatically, and one of these may be of interest. In this there is a little metal chamber, formed of very thin material and corrugated all round so that it can be elongated or shortened like a concertina. This is filled with some fluid, which expands and contracts readily with changes of temperature, and it is in contact with the hottest part of the boiler. When the heat rises, therefore, the metal "concertina" increases in length, and moves a lever connected to the damper which regulates the admission of air to the furnace and closes it, thereby damping down the fire and reducing the temperature. On the other hand, when the heat in the boiler falls, the "concertina" contracts and opens the damper so that the fire gets more air, burns more energetically, and raises the temperature. Thus the heat of the fire is so controlled that the heat in the water is fairly constant.

In some places steam is used for heating. The boiler is then only partly filled and the pipes, of course, contain no water at all. When the water is heated steam is generated and passes through the pipes, being condensed by losing its heat to the surrounding air. And here the latent heat, which is such a source of loss in the steam engine, is of great value, for because of it a little steam carries much heat. I explained in an earlier chapter how heat disappears when water is turned into steam. In fact, the amount of heat which thus becomes latent

is enough to make the water *red-hot*. It does not make it red-hot; indeed, it does not increase its temperature at all; to all appearances it disappears, but it comes back again as soon as the steam condenses. Thus steam at a very low pressure, very little above 212 degrees, is able to maintain quite a long length of piping at practically the same temperature as itself, for as it is cooled it condenses and the latent heat within it becomes liberated.

This steam-heating is often used in connection with a forced system of ventilation. Years ago people used to

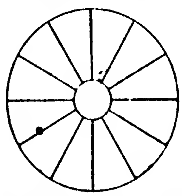


Fig. 72. Side view of the fan, with one side removed so as to show the internal divisions.

think that the heating and ventilation of factories was not a matter of much importance. In England, at any rate, there was a sort of Spartan idea that when a man was at work, he ought to be superior to any such trivial considerations as personal comfort. The fact has now become recognized, however, that good ventilation and comfortable heating are of actual money value, for people can do better work and more of it when they are invigorated with plenty of pure air and made comfortable with the right amount of heat, than they can do under imperfect conditions. Therefore factory heating has become quite an important branch of engineering, and the means generally adopted is this steam-heating in conjunction with forced ventilation.

At some suitable spot there is installed a large fan. This may be of the propeller variety; that is to say, formed of a number of blades placed round a hub like the spokes round the hub of a wheel, with their surfaces slanting, so that when the whole thing is revolved they thrust the air forward by a "screw-action," like that of a steamship propeller. More often, however, they are of a type based upon centrifugal force. There are numberless varieties of these, but one will suffice for illustration.

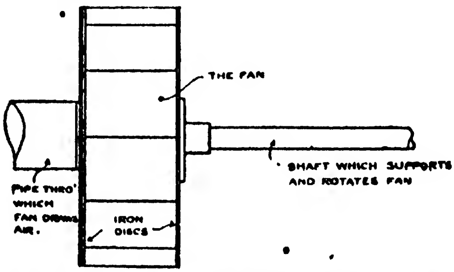


Fig. 73. Simple drawing showing the construction of a typical centrifugal fan.

Suppose two sheet-iron discs, fixed upon a shaft so that when the shaft rotates they are carried round with it. Then, between them, there are sheet-iron partitions, placed so that they connect them together, all radiating from the shaft towards the circumference. The discs and the partitions, therefore, form a number of chambers, small near the shaft but tapering outwards as they approach the edge. If such a structure be spun round upon the shaft, the air in each chamber will be thrown outwards by the centrifugal force, and more air will be drawn in at the centre to take its place.

Sometimes fans of this kind are placed in a casing

with an opening at the centre for the air to enter, and one at the edge for it to pass out. Sometimes, however, they are fixed upon the end of a shaft with the bearings on one side only, so that the fan itself overhangs and there is one side quite free from any mechanism at all. Then a pipe can be placed with its mouth close to, but not quite touching, the centre of the fan, and the fan will be able to draw air through this pipe. This latter arrangement is only useful for sucking air, however; it cannot force it, for it merely throws it out from itself into the open air. Many colliery fans are constructed in this manner.

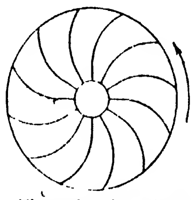


Fig. 74. This is similar to Fig. 72 but shows how the efficiency of the fan can be improved by having the divisions, or vanes, curved instead of straight.

The efficiency of such fans can be much increased by making the partitions curved, instead of simply radiating straight from the centre. Then, as anyone can see from an inspection of Fig. 74, there is a tendency to throw the air outwards, due to the shape of the partitions, as well as that due to the centrifugal force.

In applying these fans to ventilating and heating a building, they are made to force air into a chamber where there is a coil of pipes heated by steam, often the exhaust steam from the engine which drives the factory. Or else they are placed the other side of the coil, and are made to draw air through the chamber in which the coils are. In either case the heated air is compelled to pass through

ducts, which lead it to the different parts of the building. In some cases these are formed in the brickwork of the walls, just as the chimneys of houses are. In others they are large galvanized iron pipes, which are carried from floor to floor and from room to room, with suitable branches and outlets so proportioned that an approximately correct amount of pure, warm air is projected into each room.

I have seen in some Lancashire cotton mills a most ingenious method of conveying the air to the rooms. Like many large and heavy buildings, the floors are supported upon cast-iron columns, which are placed in rows down the building and which pass from floor to floor, one length upon another, from the ground to the roof. Now these columns are always hollow, for the simple reason that a hollow column can be made lighter and cheaper than a solid one of equal strength, and advantage has been taken of this. Each tier of columns is made to form a duct for the hot air. Openings are formed in them for the air to come out, and from a fan-room in the basement the warm air is driven up them into all parts of the mill.

This matter of heating and ventilation is of special importance in the cotton trade. The reason why the mills are so thickly clustered in Lancashire is because of the mild damp climate which prevails there. But for this dampness the threads break in the spinning. Now it is easy to see that the system of heating by driving air into the building, enables any desired amount of moisture to be introduced artificially into the atmosphere of the mills. The monopoly of Lancashire is therefore gone, so far as this is concerned; for the desired conditions can be produced anywhere, and the reason why the trade per-

sists in its old haunts and does not spread to the other parts of the country is based upon other considerations than that which led to its being established there originally.

This artificial humidity is produced by blowing a jet of steam into the air before it is driven into the mill. The proportion between the volume of this jet and the volume of air passing into the mill will clearly regulate the amount of moisture introduced, so that by adjusting the steam jet any desired amount can be had.

In the cotton-weaving sheds the air is blown in by a fan, but the moisture is introduced by having a network of steam pipes all over the roof. At frequent intervals there are small jets of steam thus blowing into the atmosphere of the shed.

Of course, when any system of steam-heating is employed, care has to be taken to keep the pipes free from accumulations of water. The pipes and coils are therefore arranged so that the condensed steam will naturally run back into the boiler, or else steam traps are provided, similar to those described for use in the piping of a steam engine, to let the water out automatically at any points where it might collect.

Another form of heating altogether is found in connection with certain trades where large volumes of liquid in vats or tanks need to be kept at a constant heat. A very convenient way to do this is to have coils of piping immersed in the liquid, and to keep these coils filled with steam. In some cases, even, the steam is allowed to escape directly into the water to be heated, where, of course, it condenses and gives out its latent heat. It is therefore a simple matter to heat liquids like this, particularly

water, but it is not so simple to control the temperature to that which is required, and if some automatic instrument be not employed it frequently happens that damage will be done, or the workpeople engaged in the trades concerned will be scalded by putting their hands into liquid which has been allowed accidentally to get too hot. I do not think, then, that I could do better than conclude this chapter with a description of a very interesting example of an automatic temperature regulator.

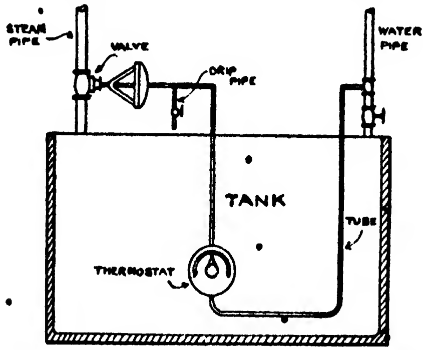


Fig. 75. This diagram shows how a thermostat can be made to control the temperature of water in a steam-heated tank.

The rectangle in Fig. 75 represents the outline of a tank, the water in which has to be kept at a constant temperature. It is heated by a coil of pipe inside it (not shown in the diagram), fed with steam by the pipe marked "steam pipe." The water for filling the tank is introduced by the water pipe, and you will notice that from this pipe a small tube is led, passing through an appliance called a thermostat, the function of which will be explained in a moment, and thence to a valve on the steam pipe. Then, and please notice this carefully, for it is more important

than it looks, just before the tube enters the steam valve there is a short branch, called the "drip pipe," with a small tap at the end of it.

So much for the apparatus. Now for the method of working. The steam valve is of the kind which is opened by pulling up a spindle and closed by pushing it in. In other words, it works like the ordinary domestic bath-tap, but with a direct push and pull, instead of through a screw. Normally it is open, but a pressure of water communicated through the tube is able, by pressing upon a flexible diaphragm, enclosed in the dome-shaped object just to the right of it, to close it.

Thus the passage of steam to the heating coils can be varied by varying the pressure of water in the tube. As the pressure increases the passage of steam is checked. Therefore, as the pressure increases the temperature of the water will be reduced. That is the first step, for if we can so contrive that the temperature of the water in the tank will regulate the pressure of water in the tube, the apparatus will be automatic.

That is the function of the thermostat. It is briefly a valve which opens when the temperature of the water in the tank increases and closes when it decreases. Now observe that the water enters the tube from the supply pipe at a point above the tap which regulates the supply to the tank, so that the first part of the tube always contains water under pressure. If it were not for the "drip," this pressure would be the same all along this tube, for the whole of it would become filled and the opening and closing of the thermostat would have no effect. Since, however, a little water can leak out through the drip, the pressure in the tube where it enters the steam valve

is always a little less than where it emerges from the water pipe; for the leak slightly relieves the pressure at that point, and the amount of that relief depends upon the relation between the opening for the water in the drip pipe and that in the thermostat. If the latter be much in excess of the former there will be little effect produced by the leak, and the pressure upon the diaphragm will be practically the same as that in the water-supply pipe. If, however, the passage in the thermostat be about equal

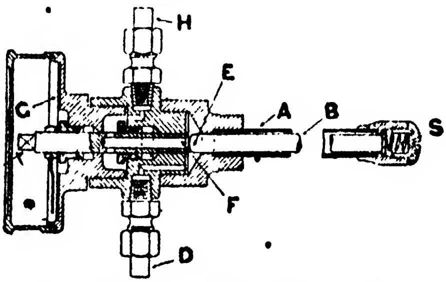


Fig. 76. This interesting little contrivance is called a thermostat. It automatically varies the flow of water from D to H in accordance with the temperature of A.

to that in the drip, then there will be little or no pressure upon the diaphragm, for the quantity of water which is able to force its way past the thermostat will find little difficulty in passing through the drip, without having to exert much pressure upon the diaphragm. Therefore the leakage at the drip having been once adjusted, the pressure upon the diaphragm will vary in accordance with the opening and closing of the water passage through the thermostat.

Fig. 76 shows us the construction of the thermostat. The water enters through the pipe D and passes upwards.

Its course can be easily traced by an inspection of the drawing. It first takes a sharp turn to the right, and enters the end of the tube F, through which it passes back towards the left. It escapes through holes in the left-hand end of this tube, passes upwards, then, through a little port, to the right upwards again, and out through the pipe H. Briefly, then, the course of the water is from D to H, by way of the tube F. Now opposite the end of F there is a rod, E, so placed that by a very little movement of E the end of F will be entirely closed.

The rod E is made of nickel steel, which does not expand and contract much under the influence of variations in heat; and it is held in a tube, A, of brass, a metal which varies a great deal with variations in temperature.

The brass tube A, with the nickel-steel rod inside it, projects through the side of the tank into the heated liquid itself, and naturally the length of the tube varies in accordance with the temperature of the liquid in the tank. The brass tube being held firmly at its left-hand end but free at the other, this variation causes the right-hand end to move to and fro, and since the nickel-steel rod inside is fixed to the brass tube at its right-hand end, it follows that the rod is pushed to and fro also, so that it more or less opens and closes the end of the tube F, and so regulates the passage of water through the apparatus.

And now we are in a position to follow the operation of this interesting invention right through. The water in the tank is getting too hot. The increase in temperature expands the brass tube A, and so draws the steel rod E to the right. That action gives the water a freer passage through the tube F. We will suppose that up to this moment the water passing through the thermostat

found a very easy escape through the drip: there would then be no pressure upon the diaphragm, and the full quantity of steam would be passing to the heating coils in the tank. As soon as the flow of water through the thermostat is increased, however, the balance is upset, and more water flows than the drip is able easily to take away. The pressure in the tube must then rise. The whole of the water passing gets out, it is true, through the drip, but not until it is forced out by pressure behind it, and that pressure is communicated also to the diaphragm, whereby the steam valve is closed somewhat, the supply of steam to the coils is checked, and the temperature of the water in the tank lowered. Then the brass tube contracts once more, slightly closing the water passage in the thermostat, relieving the pressure on the diaphragm, and so letting more steam pass, until a state of equilibrium is reached and the temperature remains steady.

It will be observed that the essential part of this apparatus is very old. It is simply the different rates of expansion in two metals, an idea which was used many years ago by Harrison in the first chronometer, so that it is at least a hundred years old, and it may be older still. Yet the apparatus just described is very up-to-date, and so we see here another illustration of the fact, which I have already remarked upon, that the inventor of to-day is largely employed in adapting to modern purposes older inventions, some of which I have already described as fundamental inventions. One is tempted to quote a well-worn phrase from the Book of Ecclesiastes, but, as it has probably sprung already into the minds of my readers, I will leave it at that.

CHAPTER XXI

MEASURING THE POWER OF AN ENGINE

It is evidently an important thing to be able to measure the power of an engine. If I have a factory, for example, and buy a steam engine to drive it, I need some means by which that engine can be tested and its strength tried, so that I may be quite sure that it is up to its work.

There are two ways of doing this. One is by means of an "indicator," which tells us the indicated horse-power, while the other, which is performed with an appliance called a "dynamometer," tells us the brake horse-power.

The indicator is another product of the fertile brain of James Watt, and consists of a little cylinder with a piston in it, the piston being pressed down by a spring. It is connected by a tube to one end of the engine cylinder, so that whatever pressure of steam there may be in the engine cylinder, there is the same in the cylinder of the indicator. Of course, at the beginning of the stroke, when the valve is fully open, there is almost the same pressure of steam in the engine cylinder and in the indicator cylinder that there is in the boiler. As soon as the valve closes, however, and the steam begins to work expansively, then the pressure in the engine cylinder falls, and the chief function of the indicator is to tell what happens in the engine cylinder during that part of the stroke. This it is able to do because its piston is pushed upwards by the steam, against the force of the spring, a distance

which is proportional to the pressure of the steam. Just as the spring in a spring balance is pulled out more or less according to the weight which is hung upon it, so the piston of the steam-engine indicator is forced upwards more or less according to the pressure of steam. And the movement of this piston operates a system of levers actuating a pencil, which presses against a moving strip of paper. In this way the indicator draws a diagram, known

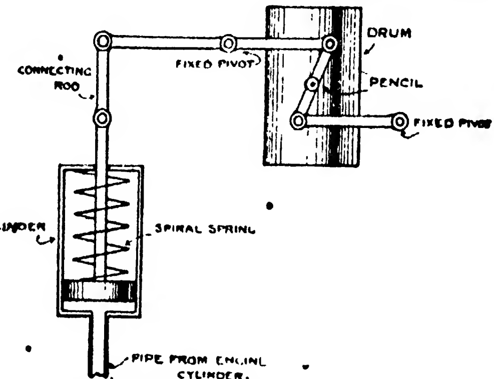


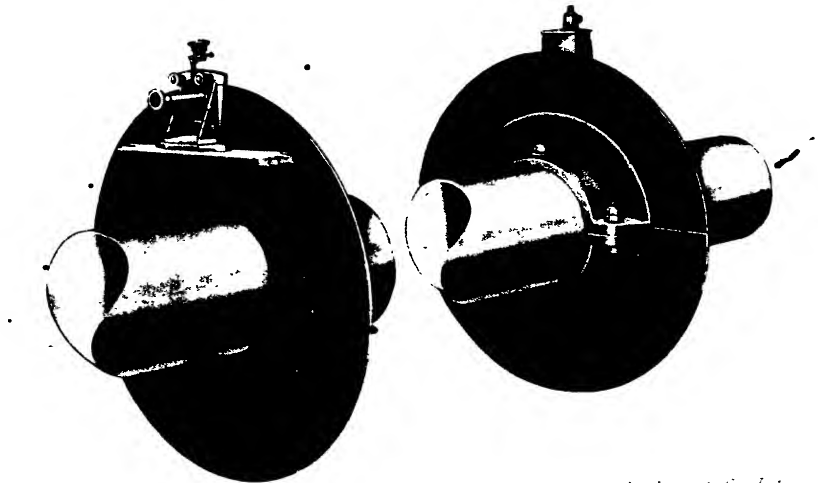
Fig. 77 Diagram explaining the working of the steam engine indicator, whereby an engine is made to write down its own character.

as an "indicator diagram," from which it is possible to find out the average or mean pressure exerted by the piston throughout the stroke. When the steam comes in first it quickly pushes up the piston, thereby drawing an almost vertical line in the indicator diagram. Then, so long as the pressure remains the same the pencil does not move, and the motion of the paper under it draws a horizontal line. As soon as the pressure begins to fall the pencil falls too, and so there is drawn a sloping line until the end of the stroke is reached, and the pressure falls to its lowest

point, which is duly recorded on the diagram. By measuring the height of the diagram at a number of points its average height can be found, and from that the average pressure. Then it is calculated that the steam pushed the piston the whole length of the stroke with that average pressure. Suppose, for example, the mean pressure was 50 lbs. per square inch and the area of the piston was 100 square inches, then the total pressure exerted on the piston throughout the stroke would be reckoned as 5000 lbs. Multiplying the length of the stroke by the number of strokes per minute gives us the distance which the steam pushes the piston in a minute, and from that we can get the horse-power, for the total pressure in pounds, multiplied by the number of feet through which the piston moves in a minute, evidently gives the number of foot-pounds per minute, and that divided by 33,000 is the horse-power.

Thus, we may say, the indicated horse-power is the amount of work which the steam does against the piston. It is not the actual work done by the engine, for there is the friction of the engine itself to take into account. We might call the indicated the " gross " horse-power and the brake the " nett," for the latter means of determining it gives us the actual work done by the engine.

Every engine is designed to work best at a particular speed. There are certain details the size of which is determined by the speed. The steam ports, for example, must be able to fill the cylinder with steam quickly and easily, in the time which is allowed for one stroke, and to get rid of the exhaust steam in the same time. Therefore, the faster the speed the larger must the ports be. And that is only one of the points which, in designing a good



By permission of *Chadburn's Ship Telegraph Co. Ltd.*

FOR MEASURING THE POWER OF A SHIP'S ENGINE

These two discs are fixed upon the propeller-shaft a few feet apart. The lamp behind the further one shines through the small slit in front of it, and through a similar slit in the other disc, into the small telescope. When the engine starts to work it twists the shaft slightly and the beam of light passing through the two slits misses the telescope altogether until the latter has been moved slightly. The amount of movement necessary is a measure of the amount of twist in the shaft, and that in turn is a measure of the power which the engine is exerting.

engine, have to be taken into consideration in the light of the speed at which the engine is to work.

It will, of course, attain this speed with little steam when it is doing no work or little work. It has then to be restrained by closing the throttle valve, or in some way depriving it of its full amount of steam. An increase of the load, however, will slow down the engine, unless more steam be given to it, so that to find out the maximum amount of work which an engine is capable of doing in a minute, we need to give it so much work to do, that with all the steam which it can take it just maintains the cor-

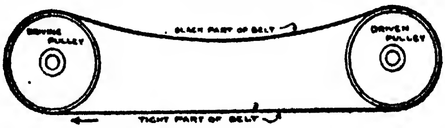


Fig. 78. Diagram showing how our pulley pulls another round by means of a belt.

rect speed. Then we need to be able to measure the amount of work which we put upon it.

In many cases an engine does its work by pulling a leather belt. The diagram Fig. 78 will show what I mean. The belt is put round two wheels, one of which (that attached to the engine) is the driving pulley, while the other (which is on the machine) is the driven pulley. The belt, by its nature, clings to the edges of the wheels, and so, when the driving wheel is turned, it pulls at one half of the belt, and that, in turn, pulls upon the edge of the driven wheel and so rotates it. One half of the belt is always taut, then, and the other slack. In other words, only one half of the belt is in action at a time, and the other half is idle. Therefore, if we could measure the pull in pounds, which the engine is giving to that half

of the belt, and multiply that by the rate at which the belt is being pulled in feet per minute, we should know the number of foot-pounds of work which the engine was doing in a minute. We can do that approximately by observing the " sag " in the middle of the belt. This sag is due to the weight of the belt itself, and knowing how much the sag is, the weight of the belt, and the distance apart of the pulleys, it is possible to calculate how tightly the belt is being pulled. The tighter it is, of course, the less will the sag be.

That is only rough, however, and in these days of refinement not good enough. Therefore we need some kind of apparatus specially designed for the purpose. One of the most up-to-date of these is known as Froude's dynamometer.

This is a kind of paddle-wheel, inside a case filled with water, which the engine is made to drive. By variations in the interior of the apparatus the power needed to drive it up to any given speed can be adjusted, and the actual power which the engine expends upon it can also be measured.

We have all of us seen a picturesque old water-wheel, and we know how the falling water there turns a wheel round. In this apparatus the operation is reversed. Here we have a very scientifically designed little water-wheel. The engine turns the wheel, and the water with which the case is filled resists its movement. In the one instance, you observe, the water turns the wheel, in the other the wheel turns the water. Were the case quite smooth on the inside it would do this quite easily, and the wheel and the water around it would soon be rotating as if they were one. There are, however, certain ribs

and cavities in the case, which correspond with similar ones in the wheel itself, and the action of the two results in the water being thrown from one to the other and back again, in such a way that the water clogs the movement of the wheel, and so makes it hard to turn round.

We can see from this, that it is the case really, and not the water, which resists the movement of the wheel. The water is simply an intermediary between the

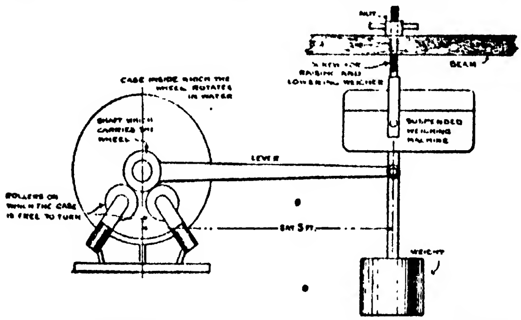


Fig. 79. This diagram explains how the hydraulic dynamometer is employed to test the power of an engine.

two, enabling the wheel to transmit its energy to the case without their being rigidly connected. Put briefly it is this. The wheel is rotating; the case is resisting it; and the power employed to turn the wheel and the resistance of the case must therefore be equal. For if the case were resisting more powerfully than the wheel was being turned, the speed would decline; or, on the other hand, if it were less the speed would increase. Therefore the resistance of the case is equal to the energy being employed to drive the wheel.

If, therefore, we can measure the resistance of the case, we shall find out what the engine is doing.

Now you cannot weigh an object by letting it lie upon the ground, but if you suspend it, so that it has a slight range of possible movement, to the end of a lever or to a spring, and then find just the force necessary to keep it from falling, the weight can be determined. In the same way, if the case were rigidly fixed we could not measure its resistance; but if it be made free to turn round a little way, and if we hold it by means of a lever,

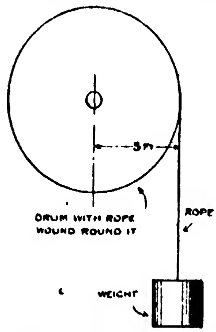


Fig. 80. This diagram helps us to see how the power of the engine is reckoned from the working of the dynamometer.

so that we *just* prevent it from turning round, then we shall know exactly what resistance it is offering to the rotation of the wheel.

The case is therefore fixed upon a centre, so that it could turn a little way were it not for a weighted lever attached to it.

If, then, we want to test the power of an engine, we couple it to the dynamometer and make it drive the wheel. Then we attach weights to the end of the lever (which we will assume is 5 feet long), until we find that the weight is just able to hold the case from being moved by the rotation of the wheel inside it. Let us imagine

that we find 200 lbs. necessary for this purpose. Then we shall know that the engine is doing work equal to lifting 200 lbs. at a leverage of 5 feet. The position will be exactly the same as if the engine were turning a drum 10 feet in diameter, with a rope wound round it and a 200-lb. weight at the end. Then, if the engine is, under these conditions, making 100 revolutions per minute, we can see that the rate at which it is doing work is equal to 200 lbs., lifted every minute, through a distance equal to 100 times the circumference of a 10-foot wheel. The result, you will find, if you care to work it out, is just over 190 horse-power.

In actual practice there is a more convenient way of finding the necessary weight at the end of the lever than actually putting weights on and off. A very heavy block of iron is generally used, part of its weight being supported by a spring balance or suspended weighing machine. The latter can be raised and lowered by a screw, so that the amount of weight which it supports can be varied, and the actual effective weight is, of course, that of the block less that which the spring balance bears. This use of a heavy block makes the apparatus steadier in operation than if just the correct weight were employed.

In the case of marine engines there is a simpler way still, constantly at hand, of determining the horse-power which the engine is developing at any moment. The engine, of course, is turning a long shaft. The screw at the other end is resisting it, and consequently there is a certain amount of twist in the shaft, an amount which is proportional to the power being transmitted from engine to propeller. It seems at first sight to be impossible that the huge steel propeller-shaft in a steamship can be

subject to actual twist, yet it is quite true. It is only small, however, and very delicate means are necessary to measure it. One of these I will describe.

At some convenient point upon the shaft are fixed two thin steel discs, from 6 to 30 feet apart. In each of these there is a small slot, and behind one of them there is placed a lamp. At some other point there is fixed to the framing of the ship a little screen, with a slot in it also, and behind its slot an "eye-piece" like that of a telescope. The whole of them are so placed, that at one point in each revolution of the shaft the light from the lamp shines through the holes in both the discs, and also through the

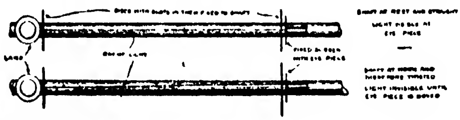


Fig. 81. Diagram showing how the power of a marine engine can be measured by the twisting of the propeller shaft.

hole in the fixed screen and into the eye-piece, so that a man placing his eye to the latter can see the light through all three holes. Under those circumstances, of course, all three holes must be exactly in line. The apparatus is thus adjusted when the shaft is not turning, and when the engine starts it twists the shaft slightly and throws the holes out of line, so that the light cannot any longer be seen through the eye-piece. To make an observation the screen and eye-piece are moved by means of a very fine screw, until once more the three holes are in line and the light can be clearly seen at each revolution. Then the distance which the screen has had to be moved forms a record of the twist which has taken place in the shaft between the two discs. The strength of the shaft to resist

twisting is known, and so from that the power which the engine is exerting can be calculated.

Similar methods to all these can be used to ascertain the power of a gas or oil engine, although the indicator is less used for that than for the steam engine. In the case of the steam turbine, however, the indicator method is not suitable, so they are always rated according to the brake horse-power.

The comparison of the indicator with the brake horse-power is very useful, for it enables us to find out what is the loss of power through mechanical friction in the engine itself. This is much reduced by the excellent modern methods of lubrication, but even now it is a formidable amount.

The relation between these two measurements is known as the mechanical efficiency of the engine. The efficiency referred to earlier, namely the proportion between the fuel supplied and the work done, is, for distinction, spoken of as the thermal efficiency.

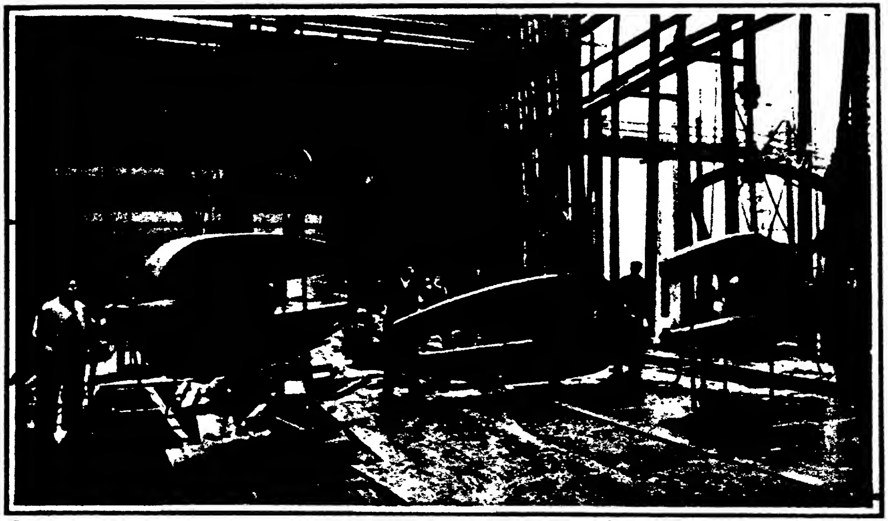
CHAPTER XXII

INVENTIONS ON THE SEA

A SHIP is itself among the most wonderful of inventions. Except in the few cases where there are several built exactly alike, every individual ship is invented separately by its designers, and a very marvellous performance it is. I do not propose to say much about that here, however. Nor do I intend more than a passing reference to the engines, which are such an important part of the modern ship, for I have had enough to say about them in earlier chapters. I want, if I can, to interest my readers in a few of the other valuable inventions, which are to be found on ships.

The mention of the engines suggests the subject of coal, and so I will start with a remarkable machine which has recently been invented for putting on board the coal needed for the engines. The idea of doing such work by machinery is not new, for transporters have been employed for years. These are really cranes, which pick up the coal out of a "collier" or a barge, either with a bucket or with a kind of mechanical hand called a grab, and then run the bucket or grab along a rope or beam and "dump" its contents into the ship.

At many places, however, the old method is employed of men carrying the coal in baskets from one vessel to the other and simply tipping it into the bunkers. Both these, the human method and the transporter, have one very



By permission of] [*Messrs. Fielding & Platt, Ltd., Gloucester.*

MECHANICAL RIVETERS

These curious machines are used for putting in the rivets when a ship is being built. They are really small presses worked by hydraulic power and they are able to squeeze even large rivets into shape with the utmost ease.

serious drawback. They cover the ship and everything in or upon it with a coating of coal dust. The state of a ship after "coaling" is almost indescribable, and the clearing up after the operation is almost as serious a matter as the loading of the coal itself.

Now this new plant, the name of which is the Suisted coal elevator, is designed to take the coal up out of a barge, lift it up to a height, and then shoot it down spouts into the ship, keeping it enclosed the whole of the way, so that the amount of dust which is able to float about and settle upon the ship is reduced to a minimum.

Facing pages 276 and 277 there are two views of the machine. It will be seen to consist of two long, narrow pontoons, carrying a superstructure of steel framework. The barge with the coal in it is floated in between the two pontoons. Then a vertical beam, similar to what is called the "ladder" in a dredging machine, is let down into it. At the bottom of this beam is a drum known as a "tumbler," around which passes a chain, which is in principle a huge bicycle chain. To the links of this chain there are fixed scoops or buckets, whichever we like to call them. The chain of buckets forms an endless band, and it is stretched over the tumbler, which has just been referred to, and also over two others at the top of the structure. The steam engine, which is a part of the plant, rotates one of these tumblers, and so causes the buckets to pass down into the barge, scoop up a quantity of coal as each one passes and carry it to the top. Then, since the chain there turns over preparatory to descending, it follows that the buckets turn over at that point and shoot out their contents.

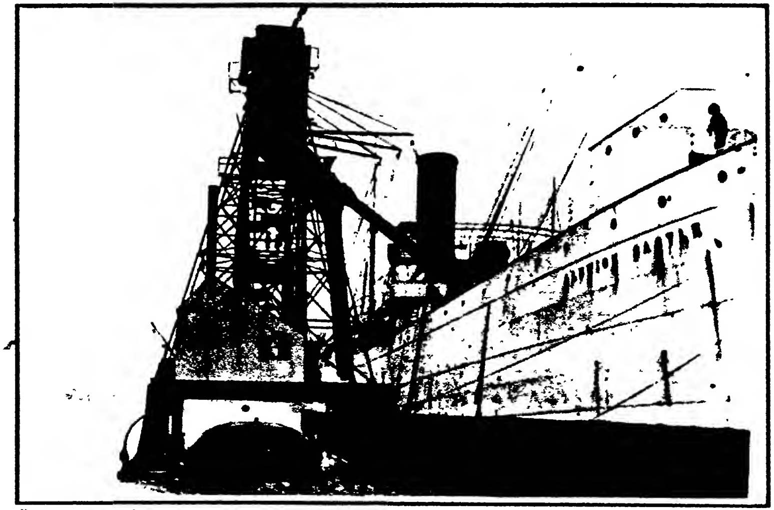
The coal falls into a hopper there, from which three long

pipes descend. These, although they are made of steel, are so constructed as to be flexible. Each one has a kind of " elbow " joint at its upper end, so that within certain limits it can be turned in any direction. Further, each one is formed in the manner which we usually associate with telescopes, one tube sliding inside another, so that the length can be varied very considerably. This means that by suitable ropes and pulleys each of the pipes can be manipulated to reach the " coaling ports " upon any ship of any size.

In operation, then, this machine goes alongside the ship to be coaled, the barge is floated into position, the pipes are adjusted to deliver the coal to the proper openings in the ship, and then the machinery is set to work. The coal is carried up to the top, shot into the hopper, and from thence falls down the pipes into the ship's bunkers ; and from the time it leaves the barge until it is shot right into the interior of the bunker it is never free, but is encased all the time.

It is arranged that the buckets shall start to scoop out the coal from the barge at one end, and as it is emptied the barge is drawn along so that the emptying operation, starting at one end, is continued right along until the whole is empty. If the barge be made with suitable sloping sides, so that the coal naturally falls to the middle, the machine could practically empty the barge without the use of any hand labour at all.

Several difficulties have been cleverly overcome in this machine. One of these is in connection with the vertical beam, as I have termed it, for want of a better name. It carries, as you will remember, the bottom tumbler, around which the buckets pass at the moment when they pick up



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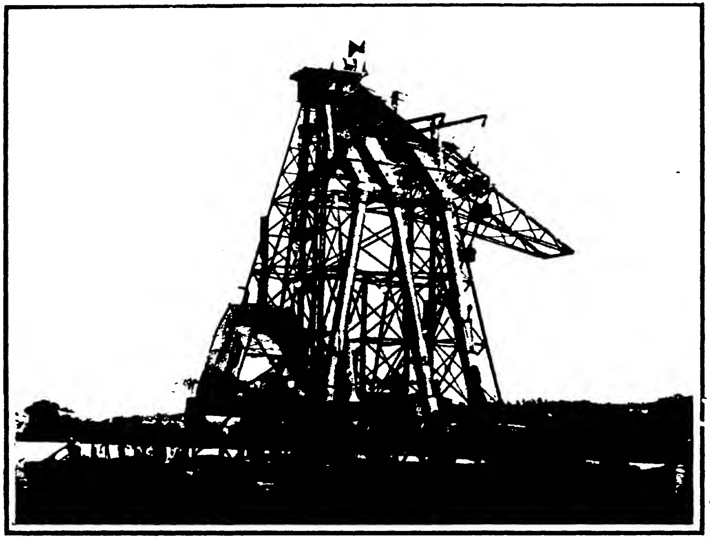
A MACHINE FOR COALING SHIPS.

Machine in position, ready for picking up Coal out of the Barge and hoisting it into three parts of the ship at once, at the rate of 100 tons an hour.



A MACHINE FOR COALING SHIPS (2)

Here we see the machine just working on trial, and a cloud of coal and coal-dust is being belched forth from each pipe.

the coal. Now this beam has to be raised to commence with, otherwise the barge could not get into place. Then it has to come down and dig its way into the coal lying in the barge underneath. Of course, there is no difficulty in making the beam rise and fall, the trouble is that it carries the bottom tumbler, and every movement causes a variation in the distance between the bottom tumbler and the

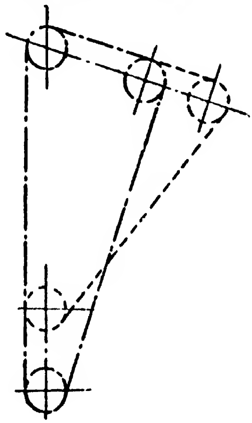


Fig. 82. This shows how the chain of buckets is kept taut. The dot and dash line represents the chain when the bottom tumbler is down. The dotted line when it is up.

top ones; and, unless it is arranged for, that must mean that the chain will be either stretched too tightly or else will be slack, when it will probably get off the tumblers and do no end of damage.

The difficulty is got over in this ingenious way. If you look at the illustration opposite you will see a kind of bracket jutting out to the right. That is for taking up the slack in the chain. The diagram Fig. 82 will make the thing clear. There we see the bottom

tumbler and the top tumbler with dotted line passing round them representing the course of the chain of buckets. But for the difficulty we are now discussing there would be no need for a third tumbler; but as it is, it is this third one which saves the situation. The bottom tumbler, let me remind you, moves up and down. The top one needs always to be near the top, so it is not convenient to move it at all; therefore, when the bottom one moves up, and so leaves the chain slack, the third one is moved to one side to compensate for it. The lower one is moved by gearing, and the third one is also moved by the same mechanism, so that they both work at the same time, and by that means the chain is always kept taut.

In the illustration opposite page 276, one can see quite easily the vertical string of ascending buckets passing from the bottom tumbler to the top in a straight line; indeed, in the upward, loaded part of their journey they are guided by steel guides, but after they have passed over the third tumbler they can be seen forming a festoon, as it were, swinging freely down to the bottom tumbler once more.

This machine can put a hundred tons of coal on board in an hour.

The time when a ship is leaving dock is an exciting and busy period for the engineers. The noise of the engines themselves, to say nothing of the various pumps and auxiliary machinery which may be in motion, sounds all the more noisy, because of the recent period of calm silence in dock. The bells of the engine room telegraph, by which the orders of the captain on the bridge are conveyed, are ringing incessantly, and the engines have to be started.

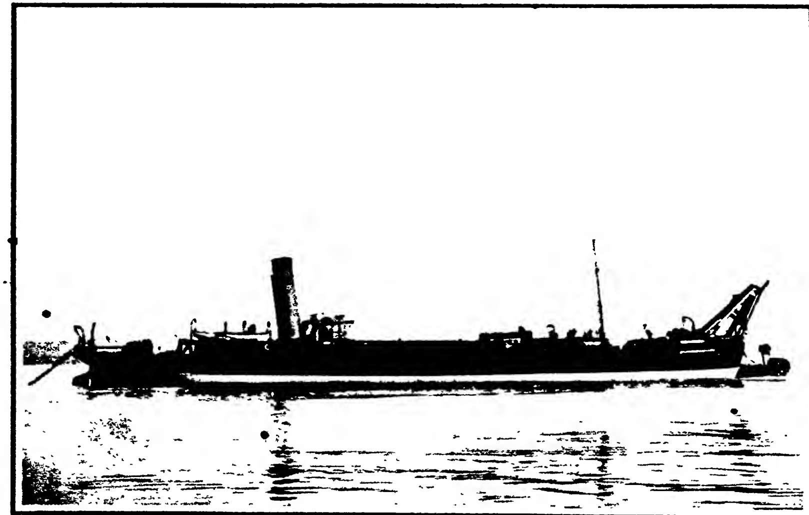
stopped, reversed, slowed down, or hurried up. The changes are continual as the great heavy vessel is slowly guided through the other ships near by or through the narrow limits of the dock gates.

Let us suppose that we are unseen observers in the engine room of a twin-screw steamship. There are two engines, one on each side of a central gangway, and from each a massive steel shaft trails away through a tunnel to the stern, there to turn a propeller fixed to its end. In the central gangway there stand four engineer officers, two to the port engine and two looking after the starboard engine. Of each pair one controls the handle which starts and stops the engine, while the other handles the reversing gear. There is a separate " telegraph " for each engine, so that the officer above can give separate orders to each, for in turning it is an advantage sometimes to have one propeller going ahead while the other goes astern. Each of these consists of a dial with a pointer in the centre, and round its edge such words as full speed, half speed, etc., and the pointer, by pointing at one of these, gives the engineers their orders. Each order, too, is accompanied by a bell sound to call attention. Each order must be acknowledged, too, by the engineer moving another pointer to the same indication which the first one is giving, so that the officer on the bridge may know that the correct signal has been received below and is being acted upon. And so these four engineers work away, making the engines obey the will of the navigator above.

But it must not be thought that the officer who reverses the engine when needed does it himself, for he would need to be stronger than even a life on the sea can make him to do that. The reversal of a steam engine, I might

explain, is accomplished by altering the action of the valves so that the steam enters *first*, at the opposite end of the cylinder. Imagine that a vertical engine is standing still at this moment. If the steam enters the top of the cylinder first the crank will be turned one way. If it enters the other end first it will rotate the other way. There are various forms of mechanism by which this alteration can be brought about, but I will not describe them here. It is enough to say that they need to be operated by some power, such as the familiar reversing lever which most readers will have seen on a locomotive. In a large engine great force is required to work the reversing gear quickly, particularly if the engine should be at work. The driver of a locomotive finds it hard work to reverse his engine by hand, and in many large engines has steam to help him. On a ship the engines are far larger than any locomotive, and so very often there is a small steam engine, whose sole duty it is to reverse the larger engine to which it is attached. This engine, acting by means of worm gearing, turns one way or the other the heavy shafts and levers which form the reversing gear.

But sometimes, instead of an engine there is simply a steam cylinder and piston, the rod of which is attached to the reversing gear. Steam can be admitted below and the piston pushed up; that turns the engine one way; or it may be let in at the top and the piston pushed down; that turns it the other way. But here a difficulty arises. The engine with its worm gear can hold the reversing gear in any desired position, for, as I pointed out in an earlier chapter, it is characteristic of worm gearing that whereas the worm can turn the wheel, the wheel cannot turn the



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A SUCTION DREDGER

This interesting craft, which belongs to the British Admiralty, is for dredging harbours and rivers to deepen the channels. The claw-like object at the bow can be let down into the water, when it cuts up the ground and enables it to be sucked up by powerful pumps on board.

worm, and so the small engine can turn the reversing gear, but the reversing gear cannot turn the small engine. With the cylinder it is quite different. When the piston has moved far enough the steam is turned off and then begins to condense. When it has condensed there is nothing whatever to hold the piston, and it is quite free to move up or down. Therefore, in such a case there is usually a

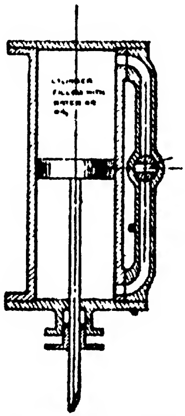


Fig. 83. Section of the hydraulic brake used to "hold" the reversing gear. When the valve is turned off (as shown) the piston cannot move.

hydraulic brake which holds the apparatus in any position into which the steam may have pushed it.

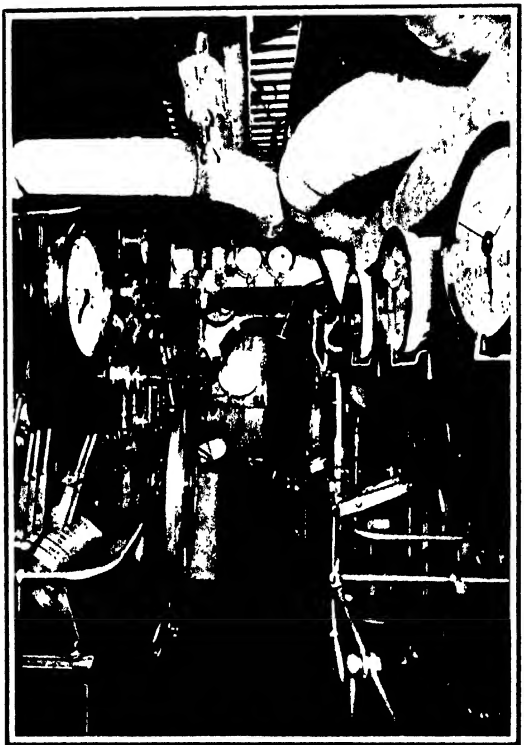
This consists of a cylinder arranged "tandem" with the steam cylinder, the two pistons being on the same rod, so that if the brake piston be held the whole mechanism will be held. The brake cylinder is filled with water or oil, and its two ends are connected together by a pipe just as the two ends of the cylinder are connected in a "Cornish" engine by the equilibrium pipe. There is a valve in

this pipe, and it is easy to see that when the valve is closed the piston is held; but when it is open, since the liquid can pass freely through it from one end to the other, the piston can move.

This valve and the one which admits steam to the steam cylinder are coupled together, so that when one is worked so is the other. Thus, whenever steam is admitted to work the reversing gear, at the same moment the other valve is opened and the brake is thereby freed; but the moment the steam is shut off the brake valve is closed too, and the reversing gear is thus held securely in the position which it then occupies.

Another invention which is very similar to this is the telemotor, by which the steering wheel is made in some ships to control the steering engine which works the rudder. In a big ship, of course, great power is needed to work the rudder. Enough, in fact, to call for the strength of a number of men, and therefore it is much better done by a special steam engine, which simply takes its orders from the motion of the steering wheel. Since sailors were so used to handling a wheel the old form of wheel has been kept to, and it looks to any observer as though the man steering a large vessel is doing it all by the strength of his own arms, just as he would be doing were it a very small boat. Stowed away, however, down in the lower part of the ship is a little engine which is doing the hard work for him.

This engine is placed generally in the engine room, or at some place where it will be out of the way and yet be able to draw a supply of steam from the boilers. And such a place is often a long way away from the bridge, and from the other places about the ship where steering wheels are installed. For on warships particularly there



By permission of [*The Cunard Steamship Co., Ltd.*

A MASS OF MECHANISM

This is the "Starting Platform" on the great Liner "Mauritania," whence the engineers control the machinery of the ship. On the left is the "Telegraph," whereby the orders of the "Autocrat on the Bridge" are conveyed to the engine-room. On the right are telegraphs by which the engineer sends his orders to those in charge of the boilers.

are a number of stations from which the ship can be steered. The problem is to connect these wheels with the steering engine, and it is found that rods or revolving shafts are not satisfactory for this purpose. One reason for this is that the rods must often pass through the watertight bulkheads or partitions, which separate the various compartments of the ship from each other, and therefore they must pass through holes in which they must fit as

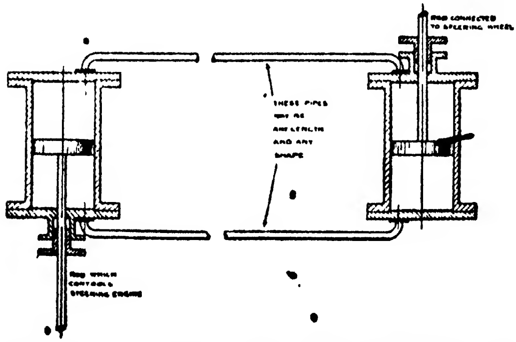


Fig. 84. Section of the telemotor by which the steering wheel controls the steering engine. Both cylinders and pipes are full of water, and consequently as one piston goes up it forces the other down, and vice versa.

a piston rod fits in the cover of an engine cylinder, for otherwise the bulkheads would cease to be watertight. And the various parts of the ship change in form with variations in temperature. Those, for example, nearest the boilers will expand more than those next the cold water, and so it was found that the rods passing thus through watertight holes would become slightly bent, and therefore hard to move.

The telemotor, however, will work just as well whatever bends may be caused in its piping, for it is worked by

water in pipes, and not by rods which slide or turn through holes.

Near the wheel there is a cylinder and piston, the former being filled with water. Near the steering engine there is a similar cylinder. The top of the "wheel" cylinder is connected by a pipe to the bottom of the cylinder near the engine, and vice versa, as shown in Fig. 84. Thus, when the action of the wheel forces down the piston in the one, the water flows along the pipes and moves the piston in the other to exactly the same extent. If the first piston is raised similar action is in like manner produced in the engine room. Thus it is exactly the same as if the wheel were directly connected to the steering engine, and since the only working part in the telemotor is water in the cylinders and pipes there is not any appreciable friction.

The steering engine is itself an interesting piece of ingenuity. Elsewhere I have ventured to call it the humorist of the engine family, and I would venture to repeat the term here, for it starts and stops, hesitates, reverses, and changes its speed under the controlling action of the steering wheel in such a way as to make its behaviour most comical to watch. It is simply a steam engine, and so needs no special description, except for the valve by which the orders of the steersman above expressed in the position of the wheel are converted into action by the engine. It is not sufficient for the turning of the wheel to open and close a valve, for with that arrangement the slightest movement of the wheel to one side or the other would open the valve and the engine would turn the rudder to its full extent unless the wheel were put back at once to the central position. The wheel would never

need to be moved more than a few inches. By a special form of controlling valve, however, the steering engine is made to move the rudder, for every revolution of the wheel, exactly that distance which it would move were the wheel connected directly to it.

CHAPTER XXIII

USELESS INVENTIONS

A STUDY of the records of any patent office will tell a pitiful tale of wasted time, energy, and skill. A man thinks of some idea. Instantly he sees fame and fortune ahead, so he fosters this child of his, spending his time and substance developing it, only to find that no one wants it, and the fortune of which he dreamed can never be realized. He stakes his " all " and loses. Business has often taken me to the library of the Patent Office in London, yet I can never enter it without an uncomfortable feeling, something akin to that which a visitor to a gambling den must experience. So many great hopes have been fostered there, only to be dashed to the ground. So many people have been there, only to find their hopes disappointed. The tragedies of the Court of Chancery are not more sad than those of the Patent Office. The unhappy story of Jarndyce and Jarndyce has had many parallels there, and the ultimate disappointment has been none the less bitter because it was due to the foolishness of the sufferer himself.

But here I want to tell of a few of the instances which have come to my own personal notice, of clever inventions which were not useless merely in the commercial sense because there was no public demand for them, but useless because doomed to fail of their purpose, since they were

based upon wrong principles. Of these, of course, perpetual motion is the most prominent.

It is a strange fact that, whereas our planet itself is an example of perpetual motion, there is no case of it *on* the planet; nor can there be, unless our basic ideas as to the construction of the things around us are altogether wrong. One of the oldest ideas was, that if a perfectly round and smooth ball were set rolling upon a perfectly smooth table, the ball would roll for ever. That implies a perfection of workmanship which has never been attained yet. It implies, too, that the ball and table must be enclosed in a perfect vacuum (for even the slight resistance which the air offers would be enough to stop the ball in time), and the perfect vacuum has yet to be made. And even supposing that it were possible to make such a ball and such a table, and to set them in a place perfectly free from air, what good would it be? The ball could do no useful work. It would be interesting to watch, and would probably make its owner's fortune as a show, until the novelty had worn off, after which no one would even pay sixpence to see it. If we tried to harness it in some way, so as to make it do work for us, we should instantly be introducing some resistance which would soon bring it to rest.

I suppose the nearest approach to perpetuity which has ever been reached is the case of a pendulum, working on roller bearings in as good a vacuum as it is possible to create. Such a pendulum has been known to go for some weeks.

The earth goes on its course without any fresh energy being imparted to it because it is free from resistance. The air is but a thin layer on the surface of the planet

itself, and beyond that there is a perfect vacuum. The invisible chains by which the earth is bound to the sun simply guide it; they cause no resistance to its motion. Therefore it seems as if it will go on with undiminished speed for ever.

The same applies to those little pieces of matter which form shooting stars. They are but minute planets, and so long as they keep a respectful distance from the earth they, too, go on with unchanging speed, but as soon as they are drawn into our atmosphere they meet with resistance, the energy which they expend in overcoming the resistance is converted into heat, and they are dissipated, their fragments falling gently upon the earth in the form of impalpable dust. Thus even the perpetual motion of the heavenly bodies is stopped as soon as they come within the conditions which prevail upon the earth.

The shooting stars are but another instance of what we were discussing in the earlier chapter upon heat, where we saw how one kind of energy can be changed into another. Heat can be turned into mechanical energy, and mechanical energy into heat, but neither can be created out of nothing; nor can energy be lost.

It can be wasted, however. All kinds of energy tend to become converted into heat. Mechanical friction of any kind causes heat. The passage of electricity through a conductor causes heat. The rushing wind heats the surfaces against which it blows, or the air of which it consists. Falling water is heated by dashing against the rocks. Many forms of chemical energy cause heat too. Indeed, all forms of energy are continually being changed into heat, and that heat tends to become evenly distributed throughout the earth.

Now when considering the subject of the heat engines, we saw that it is only a *difference* of heat which is any good to us. We need the heat of the steam boiler, contrasted against the cold of the condenser, or something equivalent to them, if we are to set heat to work for us. Heat evenly distributed is no use. Therefore the energy which is converted into heat, only to become evenly distributed, is wasted, as far as we are concerned. That is known scientifically as the "dissipation of energy."

All these facts, be it noted, have been known for so long, and have been so long subjected to the test of actual practice, that we can regard them as firmly established. They seem to be as certain as anything in the whole realm of human knowledge, and they are fatal to the success of perpetual-motion machines.

For the root idea of them is, that they should manufacture energy out of nothing. Therefore, although no one who has followed the scientific developments of the past decade would dare to say that anything is impossible, it can certainly be stated that centuries have produced no single fact which even suggests the possibility of this being done.

One scheme which was shown to me is illustrated by the diagram Fig. 85. There we have a tank of water, A, and a pipe, B, leading from near the bottom of it up to a height. There it enters the closed tank C, from which there is a small outlet, D. Just below this outlet there is a small water-wheel.

The inventor argued as follows. If, he said, the pipe B and the closed tank C be filled with water, and the outlet D opened, the water will fall from the outlet on to the turbine and drive it round. There is, he continued.

a greater weight of water in the tank C than in the pipe B, and therefore the water in the tank will descend, and that in the pipe will be drawn up, on the principle of the syphon. The water, after driving the turbine, will fall into the tank A, and will, in turn, be sucked up the pipe B, and so the thing will go on over and over again.

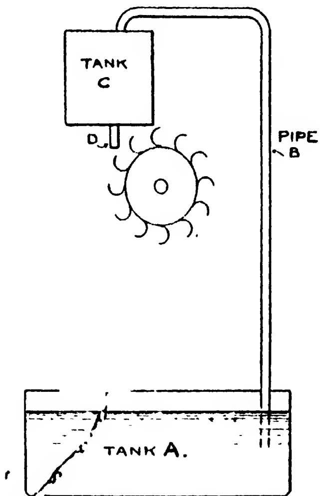


Fig. 85. A proposed perpetual motion machine.

On the face of it the proposition seems perfectly sound, but it is altogether wrong; for the water would, in fact, go the opposite way. The water will tend to flow out of the outlet, with a force due not to the total weight of water in the tank C, but only to the weight of the column of water immediately over the outlet. All the rest of the water will be supported on the bottom of the tank. Therefore the weight acting downwards in the pipe B will be greater than that acting in the tank C, and so the water

in the pipe will fall down and that in the tank will b drawn up.

Nor will any alteration in shape, size, or in any othe way of either tank or piping get over the fundamenta fact, that if you have a syphon with both legs in the sam vessel of water no flow will take place. The outlet mus be *lower* than the inlet.

Another scheme which I once saw involved the use o electricity. There was a dynamo and a motor couple together, both mechanically and electrically. That is t say, a belt connected a pulley on one to a pulley on th other, and wires carried the current from the dynamo t the motor. The essential part of the idea was, that th pulley on the motor should be smaller than that on th dynamo.

It was suggested that if such a combination were onc started, the motor would drive the dynamo mechanicall by means of the belt, while the dynamo would, in turn drive the motor by electricity. Now, of course, it i easier to drive a large pulley by means of a smaller one than it is to drive one of the same size. Therefore, con tended this ingenious inventor, the motor will hav a comparatively easy task to drive the dynamo, and s there will be a surplus of power in the motor which ca be used for some other purpose.

The weak point here is that, although the task o turning the dynamo would be made less severe by th difference in the sizes of the two pulleys, the speed woul be affected too. When two pulleys work together, eithe by means of a belt connecting them or by teeth on thei edges, or by friction between them, the result is always th same. The leverage, as explained in an earlier chapter,

will enable the smaller to turn the larger more easily than the larger could be turned directly by itself, but what is thus gained in power is lost in speed.

And, other things remaining unaltered, the current generated by a dynamo varies in proportion to the speed. Therefore, the pulley being smaller on the motor than on the dynamo, has no bearing at all on the matter, for while it makes the work easier for the motor to drive the dynamo, it also makes the dynamo less able to supply current to the motor.

As a matter of fact, electrical machines are often tested by this very means. Two machines are coupled together, as described, and they are then driven by an engine. The current generated in the dynamo helps to drive the motor, and were there no such thing as resistance and friction, the two, when once started, would drive each other. Only, it must be noted, that even then they would have no surplus power to spare. All that either could do would be needed by the other. In practice the engine has to keep on turning them, for it has to supply the power which, in both machines, is lost by mechanical friction and in electrical resistance. The energy which the engine has to supply to them, in order to keep them up to their proper speed, is therefore a measure of what they lose in themselves. If the two machines are alike this can be divided equally between the two, and so the "efficiency" of each can be determined.

Another plan which was once shown me was not for perpetual motion, but was equally futile. The idea was to utilize what was supposed to be waste power in a steam engine. It was put forward, too, by a man who had taken two high degrees at two famous universities.

The steam in a steam-engine cylinder pushes against the piston; it also pushes against the end of the cylinder. Why not make the force which is now wasted against the end of the cylinder do useful work?

That was the proposition. Its author failed to see the difference between active force and passive force. The steam does work in pushing the piston, but it does no work against the end of the cylinder. He probably thought of times when he himself had attempted to perform some physical task beyond his power, and remembered that he then did very hard work indeed. But the operation of the human body is very different from that of steam.

If we had a boiler, and heated it until the steam inside had reached, say, 100 lbs. pressure, and if we then had (which we have not) a blanket of perfectly non-conducting material which we could wrap round it, the pressure would remain at 100 lbs. for ever. It would not need any further expenditure of fuel to keep it at that; yet the steam would be pressing all the time against the side of the boiler, just as it does against the end of a cylinder.

If, however, we let the steam escape into the cylinder of an engine, *and there do work*, it will quickly lose pressure, unless we supply it with more heat. In other words, so long as no *work* is done no energy is consumed, but so soon as we begin to do work fresh energy must be put into it to keep up the supply. Therefore the pressure exerted passively upon the end of the cylinder is not in any way wasted.

Or we can see the fallacy in another way. Suppose that it takes a cubic foot of steam to push the piston 1 foot from one end of a certain cylinder towards the

other end. Then the energy consumed is the amount of heat necessary to generate that cubic foot of steam.

Suppose, next, that the cylinder were made to contain two pistons instead of one, and that the steam were admitted between them, so that there would be no force "wasted" on the end of the cylinder. The two pistons

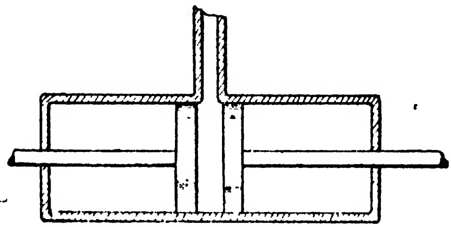


Fig. 86.

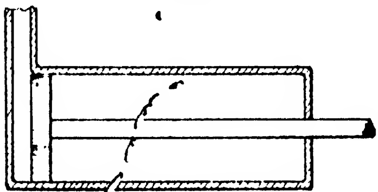


Fig. 87.

Diagrams showing that force is not wasted in pushing against the end of an engine cylinder.

would recede from one another under the pressure of the steam, and for every foot which *each of them* moved, 1 cubic foot of steam would be used. The consumption of steam will be seen, then, entirely to depend upon the part which it is pushing against *giving way before it*. If it does not move no energy is consumed.

There is another class of inventions which are useless, because they do not take into account the nature of the human being who has to use them. An illustration of

this is to be found in the rachet brace, which was referred to in an early chapter. You will remember that with that tool the workman turns the drill when moving the handle one way, but not when he moves it the other. There have been countless forms of double-acting ratchet brace invented and made, but none of them have had any success, because the inventors forgot the man who uses it. He can only exert a certain amount of energy in a certain time. Moreover, since such tools are pre-eminently intended for use in awkward places, he is often forced to work in uncomfortable positions, so that his power for work is less than usual. The return stroke, therefore, being easy, gives him a moment's respite in which to rest his muscles and prepare for the next working stroke, but with a double-acting drill he would lose that moment of relief. The only consequence would be, that he would have periodically to knock off work altogether to rest, so that with the improved tool he would do no more work than with the old one.

One could go on indefinitely adding to these useless inventions, but there is a limit to the length of a chapter, so I must be content with these illustrations. Should they meet the eye, however, of any possible inventor, I trust they may serve as a warning against the chance of becoming a useless inventor.

CHAPTER XXIV

THE INVENTION OF THE GAS ENGINE

By way of preliminary explanation, I may remark that the gas engine, and its near relative, the oil engine, are often termed internal-combustion engines. This is because the combustion of the fuel takes place, not in a separate contrivance like a boiler, but in the engine cylinder itself.

The internal-combustion engine, again, is half-brother to a gun, which may, indeed, be considered the first form of it. The gun-barrel compares with the cylinder of the engine, the bullet gives place to the piston, while the work of the gunpowder is performed by the gas. The only real difference between the two is that in the case of the engine the "bullet" is not allowed to escape from the end of the "barrel," but is brought back to its starting-point every time.

Soon after the invention of the successful steam engines of Watt, in 1807 to be precise, Sir George Cayley invented a hot-air engine in which air was expanded in a hot vessel, just as water is expanded in a boiler, and the pressure due to this expansion was used to drive an engine just as the pressure of steam does. Indeed, it was practically a steam engine driven by heated air instead of heated water. The engine itself worked a pump, which forced cold air into the hot chamber, just as a steam engine pumps cold

water into its own boiler. This type of engine will work, and has, in fact, been used to propel ships ; but it has one fatal drawback to complete success : it is liable to get too hot, and then the heat produces mechanical difficulties. The temperature employed has, therefore, to be kept comparatively low, and so, in accordance with the formula which we discussed in an earlier chapter, it is very inefficient.

Still, it has its use, for it is safe and needs no skilled attention, and so such engines are made now, but only in sizes up to about 1 horse-power, so that their usefulness is severely limited. The chief interest in Cayley's invention is that it serves to lead up to the internal-combustion engine, and it is interesting to trace the development step by step.

In 1826 another type of hot-air engine was invented, by a Dr. Stirling. In this type there is a cylinder with a piston in it like a steam engine, and a second one with a long piston called a displacer. This does not fit tightly in the cylinder, and it is not merely a disc, but a long cylindrical object, the purpose of which is to drive the air in the " displacer-cylinder " to and fro, from one end to the other. One end of this displacer-cylinder is made hot, while the other is kept as cold as possible, so that when the displacer is at the hot end (and the bulk of the air is therefore at the cold end) the air contracts, while when the displacer is at the cold end the air expands. The displacer-cylinder is connected by a pipe to one end of the working cylinder, and so, as the air expands and contracts owing to the action of the displacer, the piston is alternately pushed forward and sucked back. The same air, then, is used over and over again, there being in

modern engines of this type only one valve, and that a small one, to let in enough air to make good any lost through leakage. The action of the engine itself can, of course, be made to move the displacer just as the ordinary engine works its own valves. The same difficulty of working with a maximum temperature sufficiently high to obtain a good efficiency militates against the use of these machines also.

Next we come to the year 1850, when M. Lenoir invented an engine which forms the connecting link between the hot-air motors and the gas engines. He had a cylinder like that of a steam engine, and for the first half of the stroke a mixture of air and coal gas was permitted to enter the cylinder. Then an electric spark was caused to ignite this mixture, and the expansion which followed as the result of the burning pushed the piston the rest of the stroke. Here the question will naturally occur to the minds of most readers, what moved the piston that first half of the stroke before the combustion took place? The answer is, the momentum of the fly-wheel.

The weak point of this engine was that it used a great deal of gas, so in 1866 another appeared. This was the product of two German engineers, Langen and Otto by name, the latter of whom may almost be called the "Watt" of the gas engine. The operation of this curious engine was as follows. The piston was first lifted about a fifth of its stroke by the momentum of the fly-wheel, thus drawing in a charge of gas and air. Then the charge was ignited by the action of a slide valve, which just at the right moment uncovered a flame and allowed the gas to come into contact with it. The pressure suddenly caused by the burning drove the piston upwards until

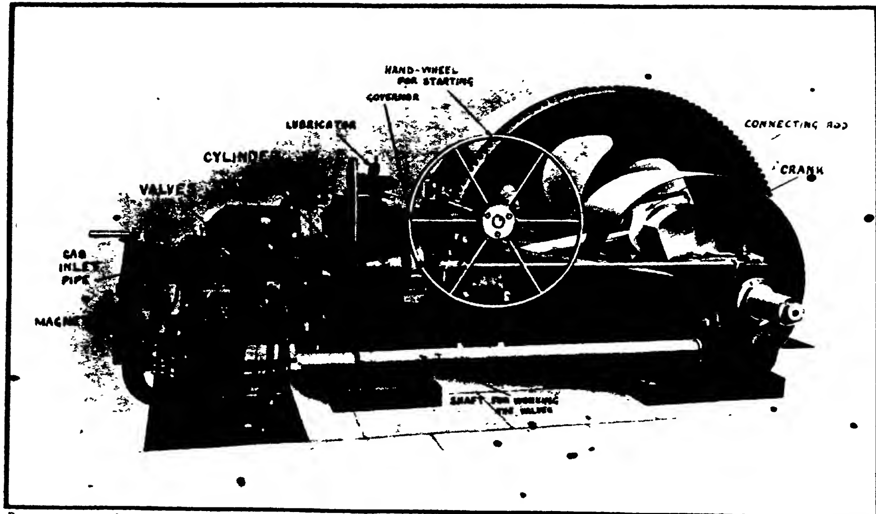
the force of the expansion was all spent. Then the momentum of the heavy piston carried it still farther, so as to cause a partial vacuum in the cylinder, under the influence of which, together with its own weight, it descended once more. When it had descended to such an extent that the partial vacuum had ceased to exist, a valve opened and the remainder of the stroke served to eject from the cylinder the burnt gases, which had, of course, to be got rid of before a second charge could be introduced. After that the same cycle of operations was gone through over again. The mechanical part was so arranged that the piston went up freely, and did its work *as it descended*. The mechanism, on the other hand, lifted the piston the first part of the stroke while it was drawing in the charge. These engines were very noisy, but they were comparatively economical; for they used only about 26 cubic feet of gas per horse-power per hour, whereas Lenoir's engine took about 96 feet.

Finally, in 1876, Dr. Otto, whom I mentioned just now, gave us the brilliant invention which has made the gas engine what it is to-day. He found that by compressing the charge of gas and air before it was fired he got an equally powerful expansion out of a weaker mixture, that is to say, out of a charge containing a smaller proportion of gas. Moreover, the expansion took place much more quietly, and the effort which it produced was more sustained: it was more uniform throughout the stroke and did not fall off so quickly after the actual burning had ceased.

And here I must interpolate a word about explosions. I have not used the term so far in connection with these engines, but have referred to what takes place as "burn-

ing." In doing so I have been quite correct, for the explosion of a gas (and, indeed, of almost all explosives) is simply the *sudden* expansion due to the *sudden* generation of heat by *sudden* combustion. Coal burns slowly and therefore does not explode, for being solid the carbon and oxygen are not mixed. Fine coal dust well mixed with air *will* explode, however, and so will gas and air, while explosives such as cordite, gun-cotton, dynamite, and the rest of them are simply solids composed of carbon and oxygen in combination, so that the moment certain conditions cause the carbon and oxygen to be separated they form an intimate mixture, and can instantly burn together, evolving great heat with a correspondingly sudden and violent expansion. Explosion, then, while it is a convenient term to describe what takes place in the cylinder of a gas engine, simply means combustion in a certain manner. We need to remember this in order to see the connection between the gas engines and the hot-air and steam engines.

And now we may enquire what are the merits of the gas engine which are enabling it to displace the steam engine in so many places. To understand this I must refer you to that formula once more, by which we calculated the maximum possible efficiency of a theoretically perfect steam engine. We took the highest practicable temperature in the steam engine as 550 degrees Fahrenheit, and the lowest as 100 degrees Fahrenheit, resulting in an efficiency of 45 per cent. Now in the gas engine we can get a temperature of about 3000 degrees Fahrenheit, and while we cannot expand the hot gases down until we get such a low temperature as we can obtain in a steam engine, we can keep them at work in the engine until they



By permission of] [*Messrs. Crossley Bros., Ltd. Manchester*

THE ENGINE OF THE FUTURE

Example of the modern Gas Engine as used for driving factories or for generating electricity. The hand wheel turns a small tooth wheel which engages in the toothed edge of the flywheel, and so the engine can be turned by hand until it is in the right position for starting.

have fallen to about 750 degrees Fahrenheit, which, working on the formula just referred to, gives us an efficiency of about 64 per cent. Therefore, looking at the matter broadly, the temperatures which we can obtain and use in a gas engine give us a better chance of making full use of the heat in our fuel than those possible in a steam engine do.

We have seen, however, that in the case of the hot-air engine there were difficulties of a mechanical kind which arose from too much heat, and the same would occur in the gas engine were not precautions taken. For this reason the cylinder has a "water-jacket" round it; there is a sort of outer cylinder formed outside the cylinder proper, and between the two water is always circulating. But for this the walls of the cylinder would soon become red hot and would be almost burnt up. The water-jacket is a necessary evil, therefore; but it is an evil all the same, for it runs away with about 50 per cent of the heat. "At one fell swoop," then, our 64 per cent is cut down by half to only 32 per cent. Against this, however, when comparing the gas engine with the steam engine we must place the fact that there are none of those losses which must accompany the use of a separate boiler, such as the heat which passes up the chimney or escapes from the boiler and the steam pipes into the surrounding atmosphere. There is none of that serious loss, too, which is due to the latent heat of steam, by which valuable heat disappears during the formation of the steam and only appears again in the cooling water of the condenser, where it is of little use. Taking all these things into consideration the actual efficiency of a good gas engine is about 25 per cent, which, low though it is, compares very

favourably with that of an equally good steam engine. After this digression we will return to the construction of the engine. The engines of Otto worked by repeating over and over again a cycle of four strokes, generally known as the "Otto cycle." The cylinder, I must explain here, is generally single-acting, that is to say, one end is open to the atmosphere and one end closed, so that the force can only be applied to the piston in one direction, instead of both ways alternately as is usual in the steam engine. Only one stroke in each cycle develops any power, the other three being preparatory only, and are due to the momentum of the fly-wheel. The first outward stroke, that is towards the open end of the cylinder, draws in the charge. The second stroke, which is, of course, an inward stroke, compresses this charge into the space at the closed end of the cylinder. Then, at the commencement of the third stroke, the explosion takes place, the piston being thereby driven violently outwards, and finally the fourth stroke of the series drives out the spent gases, after which the cycle is gone through again.

There are gas engines which are double-acting, the explosions taking place at both ends of the cylinder and not at one only, so that the piston is driven both ways as it is in a steam engine. The vast majority, however, are single-acting. Most gas engines, too, have but one cylinder, sometimes of great size; but many are made with a number of cylinders generally side by side, so that such an engine is really a number of engines having a crank shaft common to them all.

While the Otto cycle still holds the first place, there have been many attempts to contrive a two-stroke cycle. The advantage of such an arrangement is apparent, for

if an engine of given size gives out a certain power with one explosion every four strokes, it will clearly give out much more if there be an explosion every two strokes. The difficulty is to do away with two out of the four strokes of the Otto cycle. It is generally done in some

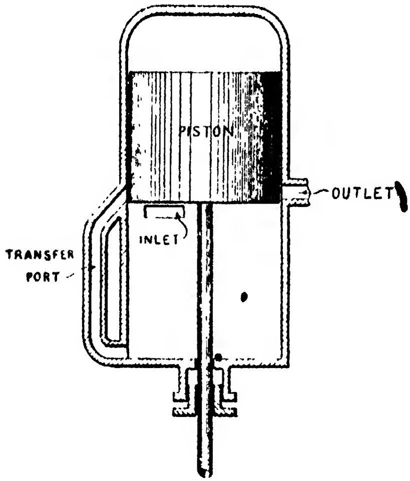


Fig. 88. This is a diagram illustrating the working of a "two-stroke" gas engine. The piston has just reached the top of its stroke and uncovered the mouth of the inlet port, through which the charge rushes in, filling the lower part of the cylinder. Descending, the piston compresses this, until the upper end of the transfer port is uncovered, when the charge rushes violently into and fills the upper part of the cylinder, at the same time driving out the waste gases through the outlet.

such way as this. The cylinder is closed at both ends, and the explosion takes place at one end, while the gas enters at the other.

As the piston approaches what we may call the "explosion end," it sucks in the mixture of air and gas at the other end. Then the explosion takes place and drives

the piston towards the "inlet end," as we might call it. Thus the charge is partly compressed during the explosion stroke. When the explosion stroke is nearly completed the compressed charge is allowed to pass through a port to the explosion end, and, owing to its having been compressed already, it naturally rushes in with great vigour, thereby driving out the spent gases of the previous stroke and filling the cylinder with a fresh charge. The piston returning compresses this again in the usual way, and so all is ready for a fresh explosion. Thus there is an explosion every time the piston reaches one end of the cylinder, or, in other words, an explosion every two strokes instead of every four. Put briefly, the charging stroke takes place simultaneously with the compression stroke, *but in the other end of the cylinder*, while the exhaust stroke is practically done away with, the partly compressed charge being transferred from one end to the other almost instantaneously at the end of the explosion stroke, the exhaust gases being driven out at the same moment.

Attempts have been made to produce a single-stroke gas engine, that is to say, one in which there is an explosion every stroke. This has generally been done by the use of a supplementary cylinder, which draws in the charge and compresses it very much as the "inlet end" of the cylinder does in the two-stroke engine. The advantage of such an engine over the two-stroke would, therefore, appear to be but little, for if there need to be two cylinders there may just as well be an explosion in each of them every two strokes as two explosions in one and none in the other. Therefore a two-cylinder engine, with each cylinder working on the two-stroke system, would

eem to be quite as good as a two-cylinder engine with one of its cylinders working on the single-stroke method, and the other doing nothing but preparatory strokes.

And this arrangement of two two-stroke cylinders has the advantage that it avoids the heating troubles which must occur when there is an explosion every stroke. Indeed, even the two-stroke engine suffers in this way. In the four-stroke cycle there is time between the explosions for the water circulating in the water-jacket to reduce the temperature and so prevent it from reaching a dangerous limit. When that interval is reduced, however, from three strokes to one it is not so easy to prevent overheating.

This question of cooling the cylinder, in an engine which depends upon heat for its motive force, is an interesting subject. As I mentioned earlier, it is the heating troubles which cripple the hot-air engine, and it may well be asked how it is that the difficulty cannot be overcome by cooling the cylinder with water in that case also. The explanation is that in the hot-air engine the heating action is practically continuous, while in the gas engine it is sudden and all over in a moment.

If a hot-air engine had its cylinder cooled sufficiently to prevent overheating, the hot air, when it entered the cylinder, would be so reduced in volume by the cooling action that it would lose nearly all its power. In the gas engine, however, the generation of heat is so sudden that the gases have expanded and done their work before the cooling action of the water-jacket has had time to neutralize the effect of the combustion. It is, of course, quite possible to conceive a gas engine working so slowly that before the end of its stroke the water-jacket could rob the

gases of their heat to such an extent, and so deprive them of their pressure, that the stroke could not be completed. The heat generated would therefore be passing almost directly from the cylinder to the cooling water without doing work, a useless state of things. Such an imaginary engine, of course, would never be met with actually; but it is simply an extreme case of what happens continually in every gas engine, and it is only the rapidity of action of the gas engine which keeps the loss of useful heat down to the 50 per cent mentioned just now.

The same difficulty has so far militated against the invention of a successful gas turbine. A charge of gas and air can easily be pumped into a combustion chamber and exploded there, and the hot gases resulting from the combustion chamber can then be led to some form of turbine; but the continual introduction of the hot fluid at the same end of the turbine, which is such an advantage in the steam turbine, causes, in the case of the gas turbine, such a high temperature to be reached as no known machine could stand for many minutes.

The gas engine can be driven by any kind of combustible gas so long as it does not form soot or other deposit in the cylinder. Coal gas, acetylene, and a cheap kind of gas called Dowson gas, or producer gas, can all be used. A cheaper gas still, the waste "fumes" from iron furnaces, is even employed to drive gas engines. Vaporized oil also forms a useful gas for the purpose, and so we come to the oil engine.

With the exception of one type, which will be described presently, these are simply gas engines with some provision for turning liquid oil into vapour. In some cases this is done in the cylinder itself. At the back end

of the cylinder, where the explosion takes place, there is great heat, and if it be arranged that the water-jacket does not come too near to that part, it is, as long as the engine is at work, amply hot enough to vaporize any oil which may be introduced. During the suction or charging stroke, therefore, the engine draws in not gas and air, but a volume of air and a few drops of oil. The oil is immediately vaporized when it comes into the hot chamber, and the vapour so formed mixes with the air and constitutes an explosive mixture similar to the charge of gas and air in the gas engine proper. In some engines, however, the vaporizer is a separate vessel (generally heated by the hot exhaust gases as they leave the cylinder) in which the oil is changed into gas, after which it is drawn into the cylinder with air exactly as the gas and air are drawn into a gas engine.

An important event occurred in 1884, when Herr Daimler brought out a light high-speed oil engine. This was further developed by Messrs. Panhard and Levassor, who, as recently as 1895, produced the petrol motor very much in the form in which it is made to-day. This little engine, again, is but a small, light gas engine, deriving its gas, the vapour of petrol, from a small, independent vaporizer, or carburettor, as it is more usually termed. This important part of the motorist's outfit needs no heat, for the liquid petrol is so volatile that it needs only to be sprayed into a chamber through a fine nozzle and brought into contact with a current of air for it to be completely changed into a very inflammable vapour. Nearly all petrol motors work on the Otto cycle, and possess all the ordinary features of the ordinary gas engine. Their special characteristics are generally connected with

their external form, which is different from the larger machines, since they are mostly for driving vehicles or small boats or flying machines, and consequently must be very compact. Often, however, they are very like an ordinary vertical gas engine. The cylinder or cylinders, for there are often several, are placed in a vertical position with their open ends downwards, the crank shaft running below them all. In other makes two cylinders are arranged like a letter "V," with the crank shaft at the apex. In one extraordinary machine designed solely for flying machines, known as the "Gnome," there are, in one size, seven cylinders, and in another fourteen, arranged like the spokes of a wheel, with the crank in the centre. The cylinders are all in one piece, and themselves revolve, while the single crank on to which they all work remains stationary. The result is, of course, precisely the same, whether the crank of an engine revolves in relation to the cylinder or the cylinder in relation to the crank. So long as one rotates in relation to the other the object of the engine, namely to produce a rotating motion, is achieved. In order, then, to save the weight of a separate fly-wheel the cylinders themselves are thus made to form their own fly-wheel, and at the same time, by their motion through the air, to cool themselves without the aid of a water-jacket. Just, too, as a number of cylinders set at different angles can push in succession at the same crank, so these revolving cylinders can all work on to the same crank.

One of the most important events in the history of the oil engine happened in the year 1900, when Herr Diesel, an officer in the Austrian Army, invented an engine which, in some respects, was quite different from anything

that had gone before. It works on a four-stroke cycle, but on the first stroke, instead of drawing in a mixture, it draws in pure air. The compression stroke compresses this to a pressure of about 500 lbs. per square inch, and the result of this compression is to raise its temperature to about 1000 degrees. Near by there is a reservoir, which, by means of a pump, is kept full of air at a still higher pressure, namely 750 to 800 lbs. per square inch, and just at the end of the compression stroke this air is made to blow into the cylinder a spray of oil. The high temperature already existing in the cylinder, because of the high pressure, is sufficient to cause this spray to burst into flame immediately. Thus *there is no explosion*, but instead, during the first part of the "power stroke," there is a *steady burning* going on in the cylinder. This results in a more sustained and uniform effort than the sudden push of an explosion, and, moreover, it provides a means of adjusting the power developed to the power required to a nicety; for all that is necessary to vary the power developed is to change the duration of the oil jet. When running light, doing no work, that is, the engine can be kept going with a mere puff of oil at the commencement of each stroke, while when it is under full load the jet can be kept up for a third, or even half, the stroke. The governor is made to vary the duration of the jet.

It is engines of the Diesel type which may form the propelling machinery for even large ships before long. The "motor battleship" is already being talked about, and if it ever materializes, this is the kind of engine which will, in all probability, be used.

Except for the Diesel engines, all gas and oil motors

need some means of firing the charge at the right moment. The first means used for this, as I have mentioned already, was the electric spark, but that was soon superseded in favour of the naked flame. Reference was made just now to an early engine which had a kind of slide-valve, which at the right moment allowed the gas to come into contact with a flame. Later, an incandescent tube came into favour. This is sometimes kept hot by a lamp outside the cylinder, while in other cases it is made to project into the pipe, through which the hot exhaust gases pass, and they are hot enough to keep it glowing. In some engines there is a valve to permit the gas to enter this tube when the explosion is required, while in others the compression is relied upon to force the gas into it just at the right time. In the great majority of cases, however, the electric spark has now displaced other methods. So we see the strange spectacle of the first method, after having been displaced, coming into favour again. Probably that is because the electric spark was less understood, and therefore not so well under control in the older days as it is now. Much progress has been made in electrical science since then, and some of the greatest electricians have not disdained to direct their efforts to improving and developing methods of bringing about the ignition of the charge in gas and oil engines. Thus the electric spark, which, compared with the hot tube, used to be fickle and unreliable, is now as certain in its action as the other, and much more easily timed, so that it shall do its work at the precise moment when it is required.

The valves of the gas engine, too, have undergone several changes. At first they were of the "slide" variety,

such as are to be found in steam engines, but they were unsuitable during the compression and explosion strokes, for then the tendency is for them to be lifted from the face upon which they slide and let the pressure down. In almost all cases, therefore, they are now of the kind shown in Fig. 14, as used in pumps. These are called mushroom valves, because of their resemblance (a remote one, it must be admitted) to the shape of a mushroom. Their special feature is that they lift easily and allow a fluid to pass through in one direction, but close tightly against any return in the opposite direction. Thus they admit the charge easily, but effectually resist any tendency for it to escape when, during the compression and explosion strokes, it is inclined to do so.

There are always two, and sometimes three, valves in the cylinder of a gas or oil engine of the ordinary type. One lets in the charge of gas and air, while another opens at the right moment and lets out the spent gases during the exhaust stroke. The third, when there is one, is used to let in the oil or gas, while the second lets in air only. Those whose function it is to let something *in* are often left to open themselves. They are simply held closed by a light spring, which the suction of the engine, during the charging stroke, is easily able to overcome. The exhaust valve, however, since it needs to be opened against pressure, in order to let something *out*, has to be pushed open by some form of mechanism operated by the engine.

There are gas engines which have no valves at all, an instance of which is typified in Fig. 88, where there are only holes in the sides of the cylinder, which are covered and uncovered by the motion of the piston itself. There

is at least one type of gas engine, too, which has a kind of slide-valve. It is known as the "Silent Knight," for it was invented by a man of that name, and its main feature is that it is free from the noise which accompanies the opening and closing of mushroom valves in an engine working at high speed.

The cylinder of this successful and remarkable engine is like three tubes one inside another. The outer one is fixed, while the others are free to slide up and down, the piston, of course, being inside the innermost one. There are holes in all three which form the inlet and outlet, and a simple mechanism, consisting of two small cranks and connecting rods, reciprocates the two inner ones, bringing holes in all three of them into coincidence when the inlet is required to be open, and three other holes on the opposite side when the outlet is required. The escape of the charge during the compression stroke, and also during the explosion stroke, is prevented by the fact that during that time the inside tube, or sleeve, as it is termed, passes up to the top of the cylinder, so that the holes are beyond the end of a plug, fitted with rings like those on a piston, which fits inside the sleeve. These rings successfully resist the tendency for the gases to escape during the moments of high pressure within the cylinder.

The story of the invention of this motor will form a fitting conclusion to this chapter, and it has been told by Mr. Knight himself. As an example of how an inventor should set about his work it would be hard to beat. His attention was directed to the subject through being annoyed by the noise of his own car. Not himself a builder of motors at that time, he approached the question with an open mind, free from the preconceived notions

which so often hamper originality. Yet he did not work in the dark, for he has said that he read every book on the subject in the English language, besides the specification of every patent relating to motors and their valves, which could be seen at the Patent Library at Washington. Thus he knew all that had been done in the past, and was able to avoid attempting to work along lines which had been tried already and had failed. Then, after all this study and long consideration, he thought of the idea outlined above, only to be met with discouragement from those who were supposed to be experts in such matters. His belief in himself and in his own idea, however, led him to pursue it in spite of everything, with the result that he achieved a signal triumph and added something quite original to the story of the invention of the internal-combustion engine.

CHAPTER XXV

THE EFFECTS OF MECHANICAL INVENTION

On reaching this last chapter I am sadly conscious of the limitations of space. I have endeavoured to give a selection of examples of invention, notable either for their importance, their intrinsic interest, or because they illustrate the general trend of the inventive faculty in things mechanical. Yet there are hosts of other interesting examples which deserve mention, but to which I have not had space even to refer. The temptation is strong, therefore, to use this final chapter in a last effort to introduce some of these to my readers' notice. On the other hand, since this book is intended to interest the general reader rather than the engineer, it seems as if one ought to review briefly the effects of mechanical invention upon the world at large.

To the engineer an invention may be interesting for two reasons. First, it appeals to his professional instincts, just as an interesting case does to those of a doctor. Secondly, it must be confessed it often interests him because it provides him with a means of making money. To the general public, however, the interest in inventions mainly lies in such questions as these: will it make my food or my clothes cheaper; will it add to my pleasures and comforts, or will it take away my work? The books which used to be put into

the hands of young boys twenty or thirty years ago dwelt largely upon the difficulties and hardships which the early inventors had to undergo. Arkwright, Hargreaves, and the rest of them were held up as heroes, who were persecuted by ignorant and misguided people, and so deprived of the honour and wealth which was their due.

Now the persecutors may have been ignorant and misguided, but the fact remains that the inventions referred to had the effect of taking from them their livelihood, and who shall blame a man for feeling angry and bitter under such circumstances. While on a visit to Preston, Lancashire, not long ago, there were pointed out to me a number of ancient houses, in which the old weavers of cotton fabric used to live before the time of the power-driven loom. All of them put together could not have produced more than a fraction of the quantity which is turned out by a single one of the large weaving sheds which are to be found in the town to-day, and in which, no doubt, many of their descendants are employed. The use of the machine has no doubt so cheapened the cost of calico, and thereby so increased the use of it, that the total sum of employment has increased, not decreased, through its introduction. But those old weavers could hardly be expected to see that. The fact they had to deal with was this: We make our living by weaving; here is a man who has invented a machine by which one man will be able to do the work now done by a hundred, what is to become of the other ninety-nine? Cheaper production, as I have said, produces a cheaper article, which in turn produces a greater demand; but that takes time, and meanwhile (even if they could see as far ahead as that)

the old weavers wondered where their food and clothing was to come from.

And, like the power-loom, the great majority of mechanical inventions are for the purpose of saving labour. The man who has a machine to sell cannot have a better selling argument than the statement that it "saves labour," or, to put it more truly, saves *wages*. The first man to adopt a labour-saving machine makes more profit, because he is able to discharge some of his hands, or he may keep his hands on and sell more at a reduced price, thereby securing a greater share of the trade and so displacing hands elsewhere. Then his competitors adopt it too, and there is a general displacement of labour all round. If the article produced is such that there is a practically unlimited use for it, this general cheapening may result, as in the case of the cotton fabrics, in an increased demand, but in some cases that is not so, and then the displacement is permanent; there is a permanent surplus of labour in that particular trade, and the younger and more active men get what jobs there are, while the older men are gradually thrown out to get on as best they can.

Then there is another result which follows the use of labour-saving machinery. An example of this is to be found in modern engineering practice. Years ago an engineering works was largely manned by skilled men called fitters. They could do anything, work a lathe or any other machine, besides doing many operations which depend mainly on manual dexterity. Such men, with labourers to help them, would build up a machine part by part, making and fitting the different pieces together as they worked. Now, in a large works, all the

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A SHIPBUILDING CRANE.

What looks like a wall at the back of the crane is the side of a ship under construction. The crane with the long arm is able to lift up pieces of material and deposit them where required, even at considerable distances away.

parts, of which a large number are required, are made separately, by men who often do nothing else. For example, if a certain kind and size of pin is required in large numbers, one man will often be employed solely to work a special machine for making them. Every part will, in fact, be made in as large quantities as possible, and the men will generally be paid piece-work; that is to say, so much per hundred or per dozen. The modern labour-saving machines which are used for this repetition work are very accurate, and are so constructed that "cheap," unskilled labour can operate them as well as skilled men could do. The result is that they are made very cheaply, and are so correct that the skilled men who actually build the machines simply have to put the parts together. It is an arrangement which produces good work and cheap work; moreover, the parts are interchangeable, and any worn or damaged at any time can be easily and cheaply replaced; but it has one great disadvantage. The fitter, and his labourer-assistants as well, under the old arrangement, feel that they are creating something, and take a pride in their work accordingly, while the man who is simply working an almost automatic machine and turning out the same thing over and over again, is simply working for his wages. There can be no question of taking a pride in such a monotonous job. The man who puts the parts together feels the same thing in a less degree, for he is only putting a number of previously prepared pieces in their proper places. The final testing and running of the machine is often done by another man altogether in another shop, so that he does not even have the satisfaction of seeing his machine at work. In all probability he never hears

anything more of it after he has done his particular routine work in connection with it, unless something is wrong.

Under the old arrangement, then, a man's work was often a pleasure to him, while under the new conditions, brought about by the advent of certain mechanical inventions, his only incentive to work is his wages and the desire to avoid the censure of his foreman.

The ideal result of the use of labour-saving machinery would be that hours of labour should decrease all round, and in a general way that may be the final effect; but it is open to question whether it is better that men should work short hours on a monotonous job than longer hours on an interesting and pleasant one. That is a subject which it would be inappropriate to discuss here, but it is food for thought. Meanwhile, the invention of labour-saving machines will go on, and they will no doubt be used more and more.

Further, if labour-saving devices account for the majority of mechanical inventions, what are left are very largely labour-wasting appliances, inventions whose object is largely to destroy. The amount of skill and human effort which is expended on preparing weapons and defences for use in wars, which, as a matter of fact, seldom happen, is appalling. Twenty or thirty years ago some of the cleverest brains in Britain were spending their time devising warships and the armament for such ships. The results of their labours are now floating in that unhappy flotilla of obsolete vessels off Portsmouth, waiting for someone to buy them and break them up. All the skill and genius which they represent, for they are full of mechanical inventions of a high order, are abso-

lutely wasted. There are indications, however, that the market for such inventions is shrinking, and there will no doubt be a time when it will cease to exist.

Thus there would appear to be a very large proportion of the mechanical inventions of to-day which are of doubtful value to the world at large, and another large proportion which are absolutely harmful. What, then, of the future? There is a vast field in which inventions are needed, and in which they can be productive of nothing but good. Those machines which, as I have pointed out, tend to displace the skilled man are of questionable social value, but those which will relieve men from the hard, degrading labours which some now have to perform will be an unalloyed blessing. The work of a stoker, for example, on a steamship is such that no man ought to be asked to perform in these enlightened days, and if the internal-combustion engine changes that, it is a result much to be desired. Anything, too, which relieves the work of the miner, working in a cramped position, often in the wet and in foul air, can be productive of nothing but good. Everything which makes a railway train more safe, or a ship more seaworthy, an improvement in a lighthouse or a lifeboat, all such inventions would be good. Then, in iron and steelworks, chemical works, and many other manufacturing institutions, there is work to be done which no one would undertake were it not for economical necessity. Those are opportunities for the inventor. If he can devise mechanical means which shall make such work less horrible, he will deserve well of his kind.

In concluding my book with this view of the subject, not from the engineer's standpoint, but from the human

side purely, I hope I have not given the impression that I depreciate in any way the valuable work done by the inventors. It is the people who invent, who have the strength and originality to go outside the beaten track, who create something which did not exist before, who make the world progress. Without them we should stagnate, or, more likely still, slip back into savagery. Yet, allowing for all that, and giving the full meed of praise to the ingenuity and originality which such people exhibit, there is another side to the question, and it is necessary that we should sometimes look at that, so that we may see where events are leading us to.

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